RESEARCHES REGARDING THE INFLUENCE OF THE COOLING TECHNOLOGY ON THE HOT ROLLED STRIPS CHARACTERISTICS AFTER ROLLING

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Abstract

This paperwork is an analyses of the industrial experiments regarding the cooling technology of the hot rolled strips as well as the correlation between mechanical characteristics and parameters that influence straightly the conducting cooling of the strips. The gotten results led to the establishing of the cooling strategies which can assures the framing of the coiling temperature in the prescribed limits alongside strips with direct implications on the mechanical and structural characteristics assurance.

1. INTRODUCTION

The cooling after rolling is one of the main technological operation to assure the structure and the final mechanical characteristics of the hot rolled strips.

To achieve the cooling in the optimum temperature range, at finishing stand exit, the strip is passing through an automatic cooling device, by water spraying, with laminar flow in upper side and under pressure in lower side, led by computer.[1] This installation is achieving on-flow thermal treatment of the strip using the temperature of the rolling end. A coiling temperature of 500…700°C results against to the quality of the rolled strips and their destination. (fig.1)

![Figure 1](image)

Figure 1 The scheme of the run-out and conducting cooling of the strip.

1- finishing stand; 2- cooling installation upper-flow (Du); 3 - cooling installation lower-flow (Dl); 4 - drawing rolls; 5 – coiler; 6 - strip

The conducting cooling of the strips, using the rolling heat is very important because the structure and mechanical characteristics of the rolled products are achieved, provided by the standards.[2]

To establish the cooling range, the following parameters are considered:

- moment speed of the strips (m/s)
- water flow (m³/h)
- cooling speed (°C/s)
The strip movement speed should be correlated to the water flow to result the established cooling speed. The strip cooling speed of the rolling end temperature is depending on the kinetics of the austenite transformation, at continuous cooling, and the ratio of the resulted constituents (ferrite + tertiary cementite, ferrite + pearlite or bainite). Water flow is determining the cooling intensity which influences strip cooling speed on one side and the after-rolling strip profile on the other side. The cooling intensity is thus expressed: \( I_c = \text{low flow} / \text{high flow} \).

The values of this ratio should be framed in the limits of \( I_c \approx 1,0 \pm 1,24 \) as strip profile to be suitable (perfect flat). At higher or lower values of this range, the strip will get a concave or convex shape.

The analyse of the conducting cooling parameters and their influence on the mechanical and structural characteristics of the strips allows the establishing of the cooling ranges on the thickness and quality steel groups.[3]

2. USED MATERIALS AND WORKING CONDITIONS

For experiments, A5 hot rolled deep-drawing steel strip was used having the following characteristics (Table 1):

<table>
<thead>
<tr>
<th>Chemical composition (%)</th>
<th>Mechanical properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>C (max)</td>
<td>Mn(max)</td>
</tr>
<tr>
<td>0,08</td>
<td>0,40</td>
</tr>
</tbody>
</table>

To establish the cooling parameters influence on the mechanical characteristics of the hot rolled strip, the recorded results have been processed statistically and the correlation between the technological parameters and mechanical characteristics have been determined.

In the industrial process, the manufacturing parameters as well as mechanical characteristics of the products, often, have a great variability that, generally, respects the function of the normal repartition.

The value of the studied characteristic for a given reliable level, was determined with relation:

\[
R_p = \bar{X} \pm Z \cdot S
\]  

Were:  
- \( R = \) characteristic value for a given probability  
- \( p = \) probability index  
- \( Z = \) coefficient to the given probability level

3. RESULTS AND DISCUSSIONS

For a given probability level of 95%, the yield point equation was established against the relation (1):

\[
R_c(95\%) = 320 \pm 1,96 \cdot S \ (N/mm^2)
\]  

For breaking elongation this relation was gotten:

\[
R_c(95\%) = 31 \pm 1,96 \cdot S \ (%)
\]
Having these relations, the variation of the mechanical characteristics against to the rolling end temperature ($T_{\text{end}}$), the coiling temperature ($T_{\text{c}}$) strip moving speed and strip cooling speed ($v_r$) have been determined. The results of the strip thickness group of $h = 2.5 \ldots 3.5$ mm are shown in figure 2.[4]

A variation could be seen; it means that yield point decreases with the increase of $T_{\text{end}}$ and $T_{\text{c}}$. The elongation increases slightly with $T_{\text{end}}$ but decreases with $T_{\text{c}}$ increase.

For the most watched heats the temperature of the rolling end is placed in the range of 840°C - 870°C and coiling temperature in the range of 530°C - 580°C. For these temperature ranges the yield point is $R_c = 220 - 230$ N/mm² and elongation $A_5 = 36 - 37\%$. 

Figure 2 Variation of the mechanical characteristics with main rolling and coiling parameters for a deep-drawing steel grade.
For same values of the characteristics $R_c$ and $A_5$, the rolling speed must be $9.6 - 10.6 \text{ m/s}$ and strip cooling speed of $4.2 - 5.5 \text{ °C/s}$.

As regards the structure, it consists of ferrite and tertiary cementite, fine scattered, uniform fine grain of point $7 - 9$.

From statistical analyses the following equation results for crystalline grains characterization.

$$N_{BLC} = 33080 - 35.5 \cdot T_{end} \quad (4)$$

Where $N_{BLC}$ - number of the grains per surface unit ($1\text{mm}^2$).

Correlation between grain-size and end rolling temperature according to equation $(4)$ is shown in fig. 3.

![Figure 3](image)

**Figure 3** Correlation between grain-size and temperature of the rolling end.

In the temperature range of $840...870\text{°C}$ a point of $8.5 - 9$ is gotten for ferrite grains. As conclusion could be said that the temperature range of $T_{end} = 840...870\text{°C}$ and $T_c = 530...580\text{°C}$ is optimum for hot rolled strips used for deep-drawing and cold rolling as a fine and uniform grain is gotten and the mechanical characteristics are framed in the restricted limits provided by the standards. To get such characteristics the establishing of the new cooling strategies of the strip after rolling mill exit are required, which was the second stage of the experiment.

A mathematical model was achieved to establish the suitable water-flows per steel grades and thickness groups. Fig. 4 and 5 show the water-flows variation at upper and lower part of the installation against to strip thickness, both: for the actual situation and those modified ones as following of the studium, as resulted from mathematical model use.
It is established that the effective flows both: in upper side and lower side have roughly constant values eventhough the strip thickness is varying in large limits of 2,10… 5,60 mm (fig.4)

Total flow was calculated by summing-up: \( D_{\text{tot}} = D_l + D_u \)

The values of the cooling intensity is varying between 0,56 … 0,8 much more under recommended lower limit.

As the final characteristics and flatness of the strips are not framed, always, in the provided limits of the standards, the modification of the cooling rate was suggested against to the strips thickness (fig. 5).

Thus, an increasing cooling flow have been used with thickness increase and, also, Du and Dl flows have approached very much. A little bit higher lower-flow than upper-flow was
used. As result, the total flow increased from 1725 m$^3$/h for $h=2.1$mm at 4313 m$^3$/h for $h=5.6$mm.

The suggested lower and higher and cumulated water-flows values have been determined respecting the condition of cooling intensity $I = 1.0\ldots1.24$ for thickness of $h = 1.59\ldots5.10$ mm to avoid strip deformation.

By modification of the water-flows, the cooling intensity $I_c = D_l / D_u \approx 1.13$ for all thickness have resulted, therefore a value that is framed in the stipulated limits ($1.0 \ldots 1.24$) for such steel-grade.

The number of the cooling valves, corresponding to the water-flows mathematically determined in base of the measured values, have been easily corrected to satisfy both: flatness conditions and uniformity of the coiling temperature alongside the strips.

It was established that some difficulties are in cooling process reproduction due to the increased scattering of the cooling water-flows values: for that is necessary the recalculation of the nominal flows and their stabilization at the same values for both: lower and upper sides.

The patterns of the cooling strategies have been achieved for each steel-grade and thickness group respecting the following conditions:

- uniform distribution of the values both: in upper side and lower side to get the cooling homogenous alongside the strip.
- operation pair assurance of each open valve in upper side with open one in lower side.

As following of the modification of the cooling installation flows on the other cooling parameters should be actioned too: $T_{end}$, $T_c$, strip speed. In the fig. 6 are shown the values of these parameters established against to the strip thickness and total cooling flows ($D_{tot}$)

![Figure 6](image)

**Figure 6** The rolling parameters variation imposed to the strip thickness and $D_{tot}$.

Finally, a higher uniformity of the characteristics and a better flatness of the strip resulted.
4. CONCLUSIONS
From the analyses made on the cooling installation operation of the hot strip rolling mill the following conclusions are detached:
- the operation of the cooling installation, respectively the upper and the lower sides don’t allow to reproduce the process at the same parameters from one strip to another, which led to the relatively large limits deviation of the mechanical characteristics.
- the achievement of the cooling strategy models and their experimental use needed the effectuation of some modifications in flow adjustment at upper and lower sides so that the value of the cooling intensity $I = 1,0 \ldots 1,24$ to be respected.
- modification of the main rolling parameters have been made: $T_{\text{end}}$, $T_c$, rolling speed. An increased uniformity of the mechanical characteristics and a better strip flatness resulted.

5. BIBLIOGRAPHY
[1] Zaharia C. s.a – Automatizarea controlului racirii cu debit laminar in laminoarele continue de benzi la cald – Sesiunea Română de Metalurgie – Brasov 2000