THERMOMECHANICAL TREATMENT OF STEEL PLATES WITH USING OF CYCLIC BENDING DEFORMATION

N.T. Egorov

Donetsk National Technical University
Ukraine, Donetsk, 83000, Artyoma str., 58
foreign@pop.dgtu.donetsk.ua

The influence of plastic deformation by multi-time bending on structure and properties of rolled plates from carbon and low-alloyed steels is considered. It is shown that deformation by cyclic bending may be successfully used for thermomechanical strengthening of plate steels. It provides obtaining of high combination of strength and toughness properties without creation of difficulties in rolling mill operation. The effect of strengthening is determined by the partial degree of deformation per single bending cycle, number of bending cycles, temperature of process and conditions of cooling as in process of deformation, as after its completion. Parameters of thermomechanical treatment of plates by multi-time bending are determined and equipment for its realization is proposed.

Introduction

Development of market economics in the sphere of manufacturing and consumption of metal products is characterized by continuously increasing demands for their quality. Extremely actual this problem is for rolled plate production, because need for this product stills on rather high level.

Traditional ways of plate steel quality increasing - alloying and heat treatment (including such effective way as quenching and tempering from separate heating in that number) does not satisfy fully as the manufacturers, as the consumers because of considerable material and energy expenses for their realization.

Formation of structure and properties of plate steels directly on-line of rolling mills is perspective and economic beneficially from the point of view of labor expenses, energy-end fuel capacity, rolled products quality and ecology [1,2].

Controlled rolling in combination with accelerated cooling obtains the intensive development in practice of rolled plates producing in recent years. To obtain the fine-grained structure, high strength, toughness and low temperature of ductile-brittle transition, controlled rolling usually must be finished in two-phase $\gamma + \alpha$ region. But it is not possible always and economically justified for many of exploited rolling mills [3,4].

At same time, rolled plates are subjected to deformation influence not only during the rolling, but in process of straightening by multiple cyclic bending.
Potential of such deformation for thermomechanical treatment is not studied well enough and does not apply in process of plates manufacturing.

**Experimental**

The influence of deformation by cyclic bending on structure and properties of steels St. 3 sp, 09G2 and 10G2S1 was studied on plates with thickness 8, 10.12 mm. Chemical composition of steels is shown in Table 1.

Table 1

<table>
<thead>
<tr>
<th>Grade of steel</th>
<th>Thickness of plate, mm</th>
<th>Content of elements, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>C</td>
</tr>
<tr>
<td>St. 3 sp</td>
<td>8</td>
<td>0,16</td>
</tr>
<tr>
<td>09G2</td>
<td>10</td>
<td>0,11</td>
</tr>
<tr>
<td>10G2S1</td>
<td>12</td>
<td>0,10</td>
</tr>
</tbody>
</table>

Deformation of plate semi products by cyclic bending was fulfilled in specially designed unit of roll-type. It permits to realize the partial degree of deformation per single bending in the range 1 – 6% in combination with different variants of accelerated cooling.

Thermoplastic treatment includes heating of plate semi products to 950 – 1050°C and alternated cycles of water and air cooling of different duration. Cyclic bending deformation was carried out during these cycles. Number of water cooling rate was 60 – 80°C/s. Temperature intervals of 700, 600 – 20°C. Number of range that provides the summary degree of

![Fig.1. Influence of partial deformation degree (ε_r) per bending cycle on strength properties of St. 3sp steel. Treatment for 4 cycles at temperatures 20, 250 and 550 °C (numbers at curves)](image)

**Discussion.**

old deformation by cyclic bending on strength is represented on Fig. 1 and 2. Effect of on by multi time bending is determined by per cycles, which are characterized the summary perature of treatment. In dependence on rs, the degree of strengthening of carbon and able and may reach 60 – 230 N/mm². Maximal place in result of deformation by cyclic – 300°C and considerably increases with mation per single bending cycle Minimal value single bending cycle is 2%, maximal – 5%.
Deformation at temperatures 700 and 750°C initiates the formation of ferrite, provides the refinement of ferrite-pearlitic structure and decreases difference in grain size and striation of steel. It results in increasing of strength, rising of impact toughness for 30 – 40% with simultaneous decreasing of anisotropy of rolled plate properties.

Plastic deformation by cyclic bending in austenitic region increases strength and toughness properties of plate steels in result of refinement of grains and formation of developed substructure.

In particular, four-time bending at temperatures 900 – 950°C with partial degree of deformation per bending 4.8% permits to obtain after quenching of steel 09G2 ultimate tensile strength and yield limit 1000 and 850 N/mm² correspondingly at elongation 10 – 12% and impact toughness at testing temperature -40°C not lower than 0.6 – 0.8 MJ/m².

In Table 2 mechanical properties of plates from steel 08G2MFB after hot rolling and thermomechanical treatment with using of deformation by cyclic bending are shown. Comparative analysis shows that combination of properties, obtained after thermomechanical treatment is characterized by combination of increased strength and toughness in comparison with controlled rolling. Uniformity of properties and flatness of plates considerably increases too.

<table>
<thead>
<tr>
<th>Type of treatment</th>
<th>$\sigma_{uts}$</th>
<th>$\sigma_{yl}$</th>
<th>$\delta_5$, %</th>
<th>$KCU^{-40^0C}$, MJ/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>10G2S1</td>
<td>240</td>
<td>160</td>
<td>80</td>
<td>10G2S1</td>
</tr>
<tr>
<td>09G2</td>
<td>20</td>
<td>40</td>
<td>60</td>
<td>09G2</td>
</tr>
</tbody>
</table>

Fig. 2. Influence of deformation by cyclic bending on strengthening of low-alloyed steels 1-G2S1 and 09G2 at temperatures of treatment, °C: 300 (a), 500 (b), 550 (c), 750 (d), 700 (e).

Degree of partial deformation per bending cycle $\varepsilon_p$:
a,b,c, - 5%; d, e – 2%
<table>
<thead>
<tr>
<th>Rolling Type</th>
<th>Temperature Range</th>
<th>Property Variation</th>
<th>Mean Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usual rolling, $T_f=1000 – 1050^\circ C$</td>
<td>550 – 590</td>
<td>370 – 400</td>
<td>26 – 29</td>
</tr>
<tr>
<td>Controlled rolling, $T_f=780 – 750^\circ C$</td>
<td>600 – 630</td>
<td>410 – 430</td>
<td>27 – 29</td>
</tr>
<tr>
<td>TMTCB, $T_{def}=500 – 550^\circ C$</td>
<td>660 – 710</td>
<td>440 – 460</td>
<td>23 – 25</td>
</tr>
</tbody>
</table>

Comment: Numerator - range of properties variation, denominator – mean value

For deformation by sign alternating bending it is typical the non-uniform distribution of it at the plate section [5]. At the same time, possibilities of thermomechanical treatment considerably extended due to the possibility to fulfill the plastic bending practically in all temperature range of plate treatment: from the finishing rolling temperature to $20^\circ C$. It is impossible to fulfill on-line of rolling mill and during the heat treatment from separate heating. In this process it is rather easy to provide optimal regimes of thermomechanical treatment with small partial deformations with minimal pauses. It permits to avoid the formation of texture and structure striation in steel, which are typical for low-temperature controlled rolling of steels.

Peculiarity and attractiveness of deformation by cyclic bending using consists of possibility to fulfill thermomechanical treatment off-line of rolling mill. It does not create additional difficulties for rolling mill operation and permits simultaneously fulfill the straightening of plate.

Best results from the point of view of strength, toughness and flatness increasing may be obtained with using of cyclic bending deformation in temperature range 900 – 500 $^\circ C$, partial degree of deformation per bending 3–4 % and number of bending cycles 7 or more. Number of bending cycles and conditions of cooling in process of deformation and after its finishing may be chosen and controlled in dependence on steel grade, its initial structure, necessary degree of strengthening and thickness of treated plate.

The roll straightening machines, which are at existent plate rolling mills, provide the partial degree of deformation per bending cycle not more than 0.5 – 0.6%, that is insufficient for effective strengthening of plates.

To realize thermomechanical treatment of rolled plates with using of cyclic bending deformation, special unit of roll type was developed. It consists of deforming and cooling sections, which contain the typical elements of quenching and straightening machines of roll type. It permits to fulfill the multi-time bending with partial degree of deformation up to 5%.

The number of deforming and cooling sections in unit is determined by set of treated steel grades, necessary combination of properties, operation conditions of rolling mill, straightening and cooling.

Equipping of plate rolling mills by units for thermoplastic treatment permits to subject to deformation-thermal treatment practically all rolled plate products with minimal expenses. This process provides considerable (up to 50 – 70%) decreasing of energy consumption, increasing of strength properties on 20 – 30%,
impact toughness 1.5–2 times with simultaneous decreasing of alloying elements content and obtaining of good flatness of plates.

Technology of thermomechanical treatment with using of deformation by cyclic bending is competitive relatively to controlled rolling or quenching and tempering. It has the set of advantages and may be recommended as perspective method of strengthening of rolled plates for general applications. In future, replacement of existing quenching units of roll type for new straightening-quenching units may be expedient.

**Conclusion**

Thermomechanical treatment of plates with using of deformation by cyclic bending considerably increases strength and toughness of rolled products from carbon and low-alloyed steels and simultaneously provides its high flatness. Best combination of properties, structure and substructure of steels may be obtained with using of cyclic bending deformation in temperature range 900–500°C, partial degree of deformation per bending 3–4 % and number of bending cycles 7 or more in combination with with different variants of controlled accelerated cooling. Conditions of process may be chosen and controlled in dependence on steel grade, its initial structure, necessary degree of strengthening and thickness of treated plate.

Using of small partial deformations with minimal pauses permits to avoid the formation of texture and structure striation in steel, which are typical for low-temperature controlled rolling of steels. It has the benefit influence on anisotropy of rolled plate properties.

Technology of thermomechanical treatment with using of deformation by multi-time bending is competitive relatively to controlled rolling and may be recommended for practical implementation. To fulfil this, equipping of plate rolling mills by straightening-quenching units for thermoplastic treatment is expedient.

**References**