ENERGY CONSUMPTION DURING THE HEAT TREATMENT OF
PLATE STEELS AND WAYS OF ITS DECREASING

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Abstract.

Current investigation is devoted to the studying of structure of energy consumption
during the manufacturing of rolled plates. Analysis was carried out on the basis of productive
experience of different metallurgical plants of Russia and Ukraine. It is shown that main
component of energy consumption is the heating of metal before the rolling. Effective ways
of energy losses decreasing are the optimization of heating regimes and using of accumulated
heat for heat treatment of plates. Developed regimes of intensive quenching and accelerated
tempering provide the decreasing of energy consumption up to 10-12% and increasing of
productivity of thermal equipment 2-3 times.

1. STRUCTURE OF ENERGY CONSUMPTION

The intensive development of industry causes the permanent increasing of demands for
energy/ In current time more than 12% of all fuel and 20% of electric energy are used for
needs of ferrous and non-ferrous metallurgy [1]. Total specific consumption of energy for
producing of rolled plates on reverse rolling mills are in the range 2836 – 5790 MJ/t in
dependence of technological operations combination. The most power-consuming operations
are the pre-rolling heating and heat treatment. Their part in total energy consumption is very
considerable and may exceed the 50-90%.

Analysis of structure of consumption of fuel and energy for heat treatment on
metallurgical integrated plants “Azovstal”, Alchevsk, Orsko-Khalilovsk, Cherepovets and
“Amurstal” plant show that main consumption of energy falls at technological fuel: natural,
blast furnace and coke gases and mazut.

Taking into account the using of different types of fuel on different metallurgical
enterprises, the technological consumption of energy for heat treatment was evaluated via
specific consumption of conventional fuel. It permits to compare the energy consumption on
different plants with necessary reliability.

Analysis shows that specific consumption of conventional fuel for heat treatment of
plates on metallurgical integrated plants deviates in wide range and consists 78-135,3 kg per
ton of physical volume of producing and 46,1 – 103 kg per ton of normalized volume of
producing. Maximal consumption took place on rolling mill 3600 of “Azovstal” integrated
plant and rolling mill 2300 of “Amurstal” metallurgical plant. High energy consumption on
“Amurstal” metallurgical plant deals with using of mazute as main fuel for continuous rolled
furnaces. On “Azovstal” integrated metallurgical plant this situation is explained by low
coefficient of furnace bottom area using because of high portion of plates with small width.
Second reason is the large volume of compelled stand idle because of rather large volume of
producing of plate steels that do nod demand the heat treatment.

Energy consumption for heat treatment of rolled plates depends on grade and size
assortment of processed plates, type and regime of heat treatment which may be characterized
by different coefficients of labor intensiveness
In Table 1 the information about specific consumption of conventional fuel on plate rolling mills is shown for different types of heat treatment. As we can see the most energy consuming operations of heat treatment are the annealing and tempering of steel.

Table 1. The specific consumption of conventional fuel for different types of heat treatment of rolled plates

<table>
<thead>
<tr>
<th>Metallurgical enterprise, rolling mill</th>
<th>Specific consumption of conventional fuel, kg per ton</th>
<th>In that number for types of heat treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Normalization</td>
</tr>
<tr>
<td>“Azovstal” rolling mill “3600”</td>
<td>135,3</td>
<td>87,8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,54</td>
</tr>
<tr>
<td>Alchevsk, rolling mill “2800”</td>
<td>85,7</td>
<td>67,8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,47</td>
</tr>
<tr>
<td>Orsko-Khalilovsl rolling mill “2800”</td>
<td>78,0</td>
<td>73,5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,5</td>
</tr>
<tr>
<td>Cherepovets rolling mill “2800”</td>
<td>107,0</td>
<td>71,2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,55</td>
</tr>
<tr>
<td>“Amurstal” rolling mill “2300”</td>
<td>123,0</td>
<td>89,1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,0</td>
</tr>
</tbody>
</table>

NOTE: Specific consumption of conventional fuel, kg per ton is shown in numerator, a coefficient of labor intensiveness is shown in denominator.

2. WAYS OF ENERGY CONSUMPTION DECREASING

Substantial decreasing of expenses for heat treatment of rolled plates may be provided in result of improvement of technology, mainly in result of optimization of “temperature - time” parameters of heating. Calculations show that decreasing of furnace working temperature during normalization and quenching from 950 to 900 °C and decreasing of specific time of heating from 1.5 to 1.0 minute per mm provides economy of conventional fuel in volume of 23-25 kg per ton of thermal treated rolled plate.

Considerable economy of energy during heat treatment may be achieved in result of effective using of rolling heating energy. Such energy-saving technology of heat treatment was developed and implemented for commercial use on “3600” rolling mill of Mariupol metallurgical integrated plant “Azovstal” for normalization of plates from carbon and low-alloyed steels in continuous roller-type furnace [2].

To obtain the optimal level of properties, provide the most favorable conditions for recyrssalization and provide the maximal utilization of rolling heating energy, the temperature of preliminary cooling of rolled sheets after hot rolling before the heat treatment is limited in the range A3 – (50 – 100) °C. For most carbon and low-alloyed steels it corresponds to interval 500 - 550 °C. Increasing of temperature of hot loading to the level of intercritical interval leads to decreasing of impact toughness after following normalization to the level of hot rolled metal (without heat treatment) or even lower (see Table 2). It causes by fact that process of austenite formation during phase recyrssalization in this case does not
accompanied by grain refinement but leads to its reduction and coarsening with formation of considerable difference in grain size.

Table 2. Mechanical properties of plates after in-line normalization with hot loading
In line of “3600” rolling mill of “Azovstal” metallurgical integrated plant

<table>
<thead>
<tr>
<th>Temperature of hot loading °C</th>
<th>( \sigma_b ) N/mm²</th>
<th>( \sigma_T ) N/mm²</th>
<th>( \delta_5 ) %</th>
<th>( \Psi_5 ) %</th>
<th>KCU, MJ/m² at temperature, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without norm.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>205</td>
<td>540</td>
<td>400</td>
<td>30.7</td>
<td>59.5</td>
<td>0.91 0.62 0.50</td>
</tr>
<tr>
<td>400</td>
<td>538</td>
<td>397</td>
<td>33.5</td>
<td>59.8</td>
<td>0.90 0.65 0.53</td>
</tr>
<tr>
<td>500</td>
<td>540</td>
<td>393</td>
<td>31.0</td>
<td>60.0</td>
<td>0.95 0.68 0.52</td>
</tr>
<tr>
<td>550</td>
<td>536</td>
<td>400</td>
<td>32.0</td>
<td>61.0</td>
<td>0.98 0.75 0.51</td>
</tr>
<tr>
<td>750</td>
<td>565</td>
<td>387</td>
<td>26.0</td>
<td>49.0</td>
<td>0.65 0.37 0.25</td>
</tr>
<tr>
<td>Steel 10GS2S1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without norm.</td>
<td>560</td>
<td>360</td>
<td>29.7</td>
<td>53.0</td>
<td>0.84 0.51 0.32</td>
</tr>
<tr>
<td>20</td>
<td>560</td>
<td>383</td>
<td>31.0</td>
<td>57.0</td>
<td>0.99 0.70 0.51</td>
</tr>
<tr>
<td>400</td>
<td>553</td>
<td>380</td>
<td>31.6</td>
<td>56.3</td>
<td>1.00 0.78 0.54</td>
</tr>
<tr>
<td>500</td>
<td>553</td>
<td>380</td>
<td>31.5</td>
<td>58.3</td>
<td>1.03 0.80 0.65</td>
</tr>
<tr>
<td>550</td>
<td>555</td>
<td>378</td>
<td>31.2</td>
<td>58.2</td>
<td>1.01 0.79 0.63</td>
</tr>
<tr>
<td>800</td>
<td>562</td>
<td>369</td>
<td>28.7</td>
<td>52.8</td>
<td>0.80 0.52 0.29</td>
</tr>
</tbody>
</table>

At observance of the optimal temperature of hot loading (500 - 550 °C) normalized rolled plates have the decreasing tendency to brittle fracture and more uniform ferritic-pearlitic structure in comparison with usual normalization [3]. Combining of regimes of regulated rolling and normalization in-line of rolling mill provides additional increasing of strength properties for 20 – 30 N/mm² and growth of impact toughness for 20 – 30%.

The using of intensive technologies of quenching and tempering is very effective from the point of resource- and energy saving. As were established by investigations, the using of two-step or interrupted cooling is most advisable for quenching of plates from low-alloyed steels. The velocity of intensive cooling during the two-step quenching is selected taking into consideration the necessity of bainite-martensitic structure formation without excessive ferrite. The stability of supercooled austenite of processed steels must be considered too. Cooling velocity consists not less than 60 – 80 °C/s in temperature range \( A_{13} - M_s \). At temperatures lower than 300 – 400 °C the cooling must be realized with velocity not more than 20 – 30 °C/s. To obtain the maximal hardenability of steels, the total water consumption for quenching of sheets in roller-type units must me not less than 150-200 m³/m²*hour.

It is most preferable to fulfill the accelerated tempering of quenched sheets with using of forced heating with using of controlled difference of temperature between metal and heating media. It may be carried out in beginning of process or during all cycle of it realization. The temperature of tempering in this case is 20 – 50 °C higher comparing with usual heating and selecting with consideration of structure after quenching, chemical composition of steel and sickness of processed sheets.

At interrupted quenching with the end of cooling in the interval of 600 – 300 °C, the temperature of accelerated tempering bay be calculated in dependence on quenching conditions according with following equation [4].
\[ T_{\text{temp}} = 787.5 + 1.25 \cdot V_{\text{cool}} - 0.25 \cdot t_{f.c.} \]

where \( V_{\text{cool}} \) – velocity of cooling during quenching, °C/s
\( t_{f.c.} \) – average mass temperature of intensive cooling interruption, °C

Developed regimes of intensive quenching and accelerated tempering provide the decreasing of energy consumption up to 10-12% and increasing of productivity of thermal equipment 2-3 times. Therefore the tendency of metallurgical enterprises to maximal economy of energy during producing of rolled plates must not to lead to decreasing of heat treatment volume, but contrary, must stimulate the development and implementation of their energy-saving technologies.

BIBLIOGRAPHY