IMPROVEMENT OF THE TECHNOLOGY OF PRODUCTION OF ZINC-TITANIUM ALLOY STRIPES

Anatoly V. Aldunin

ABSTRACT

A method of physical modeling of the structure and the physico-mechanical properties development during hot rolling of zinc-titanium alloy strips on a reversible strip mill is described.

The results obtained show that the stages of the investigated alloy softening can be identified on the basis of measuring its hardness by Vickers. They are found dependent on the temperature, the strain and the exposure time. The recrystallization diagram of the zinc-titanium alloy studied is obtained in rectifiable coordinates. The alloy physico-mechanical properties are found dependent on the total relative deformation and the initial temperature. A rolling mode providing strips suitable for deep drawing is developed.

Keywords: hot rolling of strips, zinc-titanium alloy, softening, recrystallization, physico-mechanical properties, mathematical models.

INTRODUCTION

It is known that zinc and its alloys have a high corrosion resistance [1]. Thus strips of a zinc-titanium alloy containing small additions of titanium (0.06 - 0.2 %), copper (0.08 - 0.12 %) and aluminium (up to 0.015 %) are used as a roofing material in buildings construction. It has also the advantages of being ecologically clean and easy to install. Bands of this material are produced on reversing mills on the ground of rolled billets coilers obtained on DCC units. In accordance with European standard EN 988: 1996 the physico-mechanical properties of the finished strips are determined by the regime of their partial hot rolling [2]. In Russia the production of thin strips of zinc-titanium alloy takes place at JSC “Moscow processing plant of non-ferrous metals” in accordance with a technology using DCC rolling with subsequent rolling on a reversing four-high mill 400/1000×1000 (Quarto 400). The partial hot rolling technology of this alloy strips is improved through modeling of the methods of rolling and torsion [3]. But additional annealing is required to produce a material suitable for deep drawing.

The aim of this study is to improve the technology of production of zinc-titanium alloy strips on the ground of experiments and mathematical models referring to (i) the recrystallization process under conditions of reversible hot rolling; (ii) the development of physico-mechanical properties in the course of the strips rolling.

EXPERIMENTAL

The method of physical modeling was used to study the basic regularities of the structure formation and the physico-mechanical properties development during the rolling of zinc-titanium alloy strips on 400 Quarto mill.

Wedge-shaped samples of an industrial zinc-titanium alloy (0.11 % of Cu, 0.084 % of Ti, 0.01 % of Al, 0.002 % of Cd, 0.007 % of Pb, < 0.001 % of Sn, 0.003 % of Fe, and Zn to 100%) [3] were used during the first phase of the study. 300×450 two-roll mill was employed. Samples of a size of 3(6) mm ×20 mm ×110 mm were cut from DCC (h = 7 mm) billet in the direction of rolling.

The relative deformation \( \varepsilon = \frac{h_0 - h_1}{h_0} \) and the
parameter of the hearth deformation \( m = \frac{2l_d}{h_0 + h_1} \) were accepted as geometric similarity criteria. There \( l_d \) referred to the length of the deformation zone, while \( h_0 \) and \( h_1 \) referred to the strip thickness at the crate entry and exit. The equality of the strain rates of the model and natural (existing) element, i.e. \( \dot{\varepsilon}_m = \dot{\varepsilon}_n \) was treated as a kinematic similarity. In that case, the time of the deformation of the model and natural element was identical.

All samples were heated prior to rolling at a temperature of 275°C-277°C for 45 min aiming to eliminate the effect of the heating temperature on the alloy structure. The samples were rolled at a velocity \( V = 0.36 \) m/s either immediately at a temperature of 270°C, or after air cooling at 220°C, 170°C and 70°C on 300×450 two-roll mill. After rolling and aging of 1s - 10s in air or 40 s - 600 s in a furnace heated to the rolling temperature, the samples obtained were fixed through cooling in water. The Vickers hardness (\( HV_s \)) measurements were carried out (3 - 5 measurements per point) at 5 - 7 points along the length of the rolled samples. The structure was identified at the samples’ cross sections by etching and electrochemical polishing.

The experimental data were used to estimate the mean values of hardness, \( \bar{HV} \), the root-mean-square deviations, \( S_{HV} \), and the distribution variations, \( \gamma_{HV} = S_{HV} / \bar{HV} \) [4]. A metallographic analysis of the structure was also performed.

Zinc-titanium alloy cards were rolled on 300 × 450 two-roll mill (\( h_0 = 7 \) mm, \( h_1 = 200 \) mm, \( l_0 = 180 \) mm, 120 mm and 90 mm) during the second stage of the investigation. The effect of the fractional deformation on the development of the alloy physico-mechanical properties was followed.

The cards were rolled within 1 pass, 2 passes, 3 passes, 4 passes, 6 passes and 8 passes (\( V = 0.36 \) m/s) at a rolling initial temperature of 150°C, 190°C and 270°C. The pauses were 32 s - 33 s. Air cooling was applied after each rolling.

Prior to the rolling the card was heated for 45 min in the ranges of 175°C - 185°C, 210°C -220°C or 280°C - 290°C, and then cooled in air to the rolling temperature used. The process of cooling was followed using a contact thermometer “RKC2” brand “DP 200”. The temperature reading was carried out twice after each pass.

Longitudinal samples (3-5 samples per card) were cut from the rolled and the air-cooled maps for tensile tests proceeding in accordance with GOST 1497-73, as well as for Vickers hardness testing (3 - 5 measurements per sample). Transverse samples (3 - 5 samples) were cut out for tensile tests from the maps rolled within 6 passes and 8 passes.

**RESULTS AND DISCUSSION**

The dependences of the average hardness value \( \bar{HV}_5 \) of wedge-shaped samples rolled at \( t = 270°C \) versus the relative deformation \( \varepsilon \) at constant time \( \tau \) are presented in Fig. 1.

Deformation hardening is observed in case of relative deformation \( \varepsilon \leq 22\% \). The hardness decreases significantly from \( 52 HV_s \) to \( 48 HV_s \) when the deformation is greater than 22%. This indicates softening due to static recrystallization. For this alloy the value of \( \varepsilon = 22\% \) is critical. Thus, the weakening of the alloy investigated can be identified on the basis of its hardness.

The metallographic analysis of the laminated samples reveals the occurrence of microcracks at the grain boundaries at a relative deformation \( \varepsilon = 20\% \) (Fig. 2) oriented at an angle of ca 45° to the main normal stress.

![Fig. 1. Dependence of the hardness \( \bar{HV}_5 \) of zinc-titanium alloy samples rolled at 270°C versus the relative deformation \( \varepsilon \) at constant time \( \tau \).](image-url)
principal shear stresses. The micro-cracks detected at small exposures after deformation (τ ≤ 1 s) can not «heal».

All versions of the samples rolled are also analyzed in coordinates “t – ɛ – τ” in respect to the hardness parameters (HV₁, HV₂, HV₃) and the structure of the material. The recrystallization diagram (Fig. 3) of the zinc-titanium alloy studied is obtained in rectifiable coordinates 1/T – lg ɛ – lg τ [5].

The boundaries of the regions in the diagram presented are described by the equation:

\[
\frac{1}{T} 10^4 = a_0 + a_1 \lg \tau + a_2 \lg \varepsilon
\]

(1)

The values of the coefficients of Eq.(1) estimated with a probability P = 95 % and a significance level α = 0.05 are shown in Table 1.

The residual error \( S_{res} \) of Eq. (1) does not exceed 2,802.

The graphic dependences of the rolling temperature \( t \), as well as the strength \( \sigma_{ts} \) and the elongation \( \delta \) of the zinc-titanium alloy versus the number of passes (the total relative deformation, \( \varepsilon_r \)) are obtained on the ground of the experiments carried out at different initial temperature of rolling, \( t_{s.r.} \) (Fig. 4).

The rolling of cards within 1 pass to 8 passes at different values of \( t_{s.r.} \) (150°C, 190°C and 270°C) and constant pause between the compressions, \( \tau_p \) (32 s - 33 s) shows that the final rolling temperature, \( t_{f.r.} \), is practically independent from \( t_{s.r.} \). It amounts to 38°C - 43°C. The convective heat transfer from the cards to the rolls as well as the radiation transfer to the air observed during the first four passes when the initial rolling temperature is increased from 150°C to 270°C are much higher than the thermal effect of the plastic deformation.

There is a rapid decrease of \( \sigma_{ts} \) from 290,1 MPa - 299,6 MPa to 167,2 MPa -180,1 MPa at a practically unchanged \( \delta \) when the number of passes is greater than six in case the total relative deformation \( \varepsilon_r > 81,4 \% \). This intensive softening of the material deformed, probably due to rupture of the dislocations previously blocked by the dispersed phase particles and their release to the grain boundaries [6]. In presence of a twin structure, a second mechanism of weakening-an accommodative

<table>
<thead>
<tr>
<th>Borders of areas</th>
<th>( a_0 )</th>
<th>( a_1 )</th>
<th>( a_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A – B )</td>
<td>20,8509</td>
<td>2,2445</td>
<td>6,6249</td>
</tr>
<tr>
<td>( B – C )</td>
<td>19,0120</td>
<td>2,2124</td>
<td>5,8815</td>
</tr>
</tbody>
</table>

Table 1. Values of the coefficients of Eq. (1) referring to the boundaries of regions A - B and B - C.
throw is possible [7].

The main regularities connected with the development of the mechanical properties of the zinc-titanium alloy studied are processed by the regression analysis methods [4]. The results referring to rolled cards (1 pass - 8 passes) are used.

The regression equations determining the time of resistance $\tau_{p}$ and the elongation $\delta$ of the zinc-titanium alloy studied are obtained in case of $t_{s.r.} = 150^\circ C - 270^\circ C$, $\epsilon_c = 29,6% - 91,4%$ at $\dot{\epsilon}_{m} \approx 10 \text{ s}^{-1}$, $\tau_p = 33s - 35s$

$c_1 t_{s.r.} = 38^\circ C - 42^\circ C$

with a probability of $P = 95\%$ and a significance level of $\alpha = 0.05$. They are of the form:

$$\sigma_{ts} = 724,07 - 23,56 \cdot \epsilon_{\Sigma} + 0,0076 \cdot \epsilon_{\Sigma}^3 - 0,0001 \cdot \epsilon_{\Sigma}^4 + 38,71 \cdot \cos(\epsilon_{\Sigma})$$

$$\delta = -33,20 + 2,87 \cdot \epsilon_{\Sigma} + 0,0164 \cdot t_{s.r.} - 0,0459 \cdot \epsilon_{\Sigma}^2 + 0,0003 \cdot \epsilon_{\Sigma}^3$$

where $\epsilon_{\Sigma}$ is the total relative deformation (%), while $t_{s.r.}$ is the initial rolling temperature (ºC). The correlation coefficients $R$ refer to 0,9264 for Eq. (2) and 0,9188 for Eq. (3).

Eqs. (2, 3) provide the prediction of the physical and mechanical properties of the strips rolled on Quarto 400 reversing mill.

The results of this investigation are used for the development of hot rolling of 0.7 mm ×750 mm strips of titanium-zinc alloy on Quarto 400 reversing mill at Moscow processing plant of non-ferrous metals (Table 2).

The completion time of the primary recrystallization, $\tau_{r}$, calculated according to Eq. (2) does not exceed the pause time between the passes, $\tau_p$. Thus, this mode provides the production of ready-made strips of a fairly isotropic structure (a coefficient of an anisotropy structure and physico-mechanical properties $r = 0.95$ to 1.00) and high ductility. This allows the application of the rolling mode described as a billet for getting parts by deep drawing during sheet stamping with no additional annealing.

---

**Table 2.** Mode of hot rolling of zinc-titanium alloy (0.7 mm ×750 mm) strips on Quarto 400 mill of Moscow plant of nonferrous metals processing.

<table>
<thead>
<tr>
<th>Passage number</th>
<th>$h_0$, mm</th>
<th>$h_1$, mm</th>
<th>$\epsilon$, %</th>
<th>$V$, m/s</th>
<th>$\dot{\epsilon}$, s$^{-1}$</th>
<th>$t$, ºC</th>
<th>$\tau_r$, s</th>
<th>$\tau_p$, s</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7,0</td>
<td>6,3</td>
<td>10,0</td>
<td>0,8</td>
<td>7,1</td>
<td>350</td>
<td>-</td>
<td>115</td>
</tr>
<tr>
<td>2</td>
<td>6,3</td>
<td>5,2</td>
<td>17,5</td>
<td>0,9</td>
<td>11,6</td>
<td>322</td>
<td>-</td>
<td>112</td>
</tr>
<tr>
<td>3</td>
<td>5,2</td>
<td>3,9</td>
<td>25,0</td>
<td>1,0</td>
<td>17,7</td>
<td>297</td>
<td>8,6</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>3,9</td>
<td>2,7</td>
<td>30,8</td>
<td>1,2</td>
<td>28,2</td>
<td>275</td>
<td>10,3</td>
<td>190</td>
</tr>
<tr>
<td>5</td>
<td>2,7</td>
<td>1,8</td>
<td>33,3</td>
<td>1,3</td>
<td>38,8</td>
<td>255</td>
<td>17,2</td>
<td>275</td>
</tr>
<tr>
<td>6</td>
<td>1,8</td>
<td>1,3</td>
<td>27,8</td>
<td>1,3</td>
<td>41,9</td>
<td>237</td>
<td>55,8</td>
<td>360</td>
</tr>
<tr>
<td>7</td>
<td>1,3</td>
<td>0,95</td>
<td>26,9</td>
<td>1,3</td>
<td>48,3</td>
<td>222</td>
<td>113,2</td>
<td>480</td>
</tr>
<tr>
<td>8</td>
<td>0,95</td>
<td>0,7</td>
<td>26,3</td>
<td>1,3</td>
<td>55,7</td>
<td>210</td>
<td>202,4</td>
<td>650</td>
</tr>
</tbody>
</table>
CONCLUSIONS

The stages of the softening and of the structure formation of zinc-titanium alloy during hot rolling can be identified on the basis of measurements of its hardness by Vickers.

The application of the mathematical models developed on the ground of the experimental results provide to determine the technological modes of hot rolling of zinc-titanium alloy strips aiming to obtain the required structure and physico-mechanical properties.

REFERENCES