ANALYSIS OF METAL FLOW DURING ROLLING OF Z-SECTION SHEET PILE

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Abstract

Paper contains the analysis of metal flow during rolling of long products, especially in regard to fill in a compound grooves. As the specific examples for investigation have been chosen Z-section sheet piles. These steel sections belong to long rolled products, which have a great demand on steel market. From one side, the rolling process of sheet piles is very profitably, but from the other one the rolling technology is highly difficult. During designing the rolling process, i.e. the proper filling of the grooves, distribution of reductions for individual passes and parts of the profile, the principles of both physical modelling and FEM simulation have been applied. The results of laboratory tests and simulations carried out in the work are discussed. The realized study allowed to make proper roll pass design with the correct grooves as well as to elaborate better pass schedule for rolling accurate products in industrial conditions.

Keywords: rolling of sheet pile, metal flow, roll pass design

1. INTRODUCTION

There is a great demand for sheet piles on the steel marked, considering their utilization properties. From decades millions tons of these sections have been used all over the world for every kind of structure. Regarding the shape of cross section, the most often produced types of these profiles are following, Fig. 1:

- straight web sheet piles,
- U-section sheet piles,
- Z-section sheet pile.

Fig. 1. Typical shapes of hot rolled sheet piles
The straight web sheet piles are often used to form cylindrical structures for retaining a soil fill. Depending on the site characteristic, the circular cells or diaphragm cells are form using these sections. Both, U-section and Z-section have been used for many kind of structures, mainly in the civil engineering. Among the various sheet piles Z-section ones play the primary role. The advantages of Z sheet piles are multiple, the most known ones are the following:

- high width resulting in good installation performance,
- very high competitive section modulus to mass ratio,
- increased interia, reducing deflection and allowing high yield steels to be used,
- good corrosion resistance due to thickest parts at the critical corrosion points.

From one side, the above mentioned advantages make the rolling process of sheet piles very profitably, but from the other one the rolling technology is highly difficult [1-3]. The study presented in the paper allowed to design proper hot rolling process with adequate pass schedule, as well as to elaborate roll pass design for rolling accurate products in industrial conditions.

1. PROCESSING AND MATERIAL CHARACTERISTIC

The hot rolling process is typically used for production of sheet piles, including Z-section ones. They are very wide and thin products and their cross section has any axis of symmetry. Furthermore, the interlocks on both sides of profile must be exactly formed during rolling. This implies that during rolling of such sections exists both high vertical and high axial forces. Moreover these sections are likely to bend and to twist at the exit from rolls [1,3]. The heavy section mills equipped with adequate stands are suitable for rolling such products. The typical technology of Z sheet pile production may use the following types of incoming material:

- slab with rectangular cross section from continuous casting,
- beam blank with so called “dog bone” cross section, also from continuous casting.

![Fig. 2. Schematic view of grooves used for rolling of Z-section sheet pile](image-url)
Nevertheless, both the slabs and the beam blanks have many disadvantages, regarding their shape. However, the technology that seems to be prevailing in the future will use the beam blanks. At least ten shaped grooves have to be used for rolling Z-section of typical width (600 or 700 mm), Fig. 2. The total number of passes depends on stands characteristic and can attain from 17 up to 19 passes. It implies that at initial grooves (up to 5-th) several passes have to be realized in individual groove [4].

The steel grades for hot rolled sheet piles is standardized by norm EN 10248 part 1. On request can be used steel grades complying with other standards or steel with an improved corrosion resistance, or copper addition. The mechanical properties and chemical composition of steel grades according to EN 10248 are shown in the table 1.

<table>
<thead>
<tr>
<th>Grade</th>
<th>$R_e$, min</th>
<th>$R_m$, min</th>
<th>$A$, min</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>N</th>
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<tr>
<td></td>
<td>MPa</td>
<td>MPa</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
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<tr>
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<td>-</td>
<td>-</td>
<td>0.055</td>
<td>0.055</td>
<td>0.011</td>
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<tr>
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<td>270</td>
<td>410</td>
<td>24</td>
<td>0.27</td>
<td>-</td>
<td>-</td>
<td>0.055</td>
<td>0.055</td>
<td>0.011</td>
</tr>
<tr>
<td>S 320 GP</td>
<td>320</td>
<td>440</td>
<td>23</td>
<td>0.27</td>
<td>1.70</td>
<td>0.60</td>
<td>0.055</td>
<td>0.055</td>
<td>0.011</td>
</tr>
<tr>
<td>S 355 GP</td>
<td>355</td>
<td>480</td>
<td>22</td>
<td>0.27</td>
<td>1.70</td>
<td>0.60</td>
<td>0.055</td>
<td>0.055</td>
<td>0.011</td>
</tr>
<tr>
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<td>390</td>
<td>490</td>
<td>20</td>
<td>0.27</td>
<td>1.70</td>
<td>0.60</td>
<td>0.050</td>
<td>0.050</td>
<td>0.011</td>
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<tr>
<td>S 430 GP</td>
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<td>510</td>
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<td>0.27</td>
<td>1.70</td>
<td>0.60</td>
<td>0.050</td>
<td>0.050</td>
<td>0.011</td>
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<tr>
<td>S 460 AP*</td>
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<td>550</td>
<td>17</td>
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<td>1.70</td>
<td>0.60</td>
<td>0.050</td>
<td>0.050</td>
<td>0.011</td>
</tr>
</tbody>
</table>

*) Uppon request, mill specification.

2. PLASTOMETRIC TESTS AND PHYSICAL MODELLING OF SHEET PILE ROLLING

2.1. Plastometric tests

Prior to computer simulations a series of tests were performed using torsional plastometer [5]. The samples for all tests were prepared from steel grade S 430 GP. The mechanical properties and chemical composition of this steel according to the standard EN 10248 is presented in Tab. 1. The obtained results in a form of flow stress variations as a function of temperature, strain and strain rate have been loaded into computer program as the material database. The example flow stresses for S430GP steel are presented in Fig. 3.

![Flow stresses of S430 GP steel grade obtained from torsion tests for various temperatures (in °C) and strain rate equal 2 s⁻¹](image-url)
The performed plastometric tests allowed for determining the changes of flow stress as a function of temperature, strain, and strain rate. Prior to further calculations and tests, these relationships were stored in the material database of finite element method (FEM) program.

1.1 Physical modelling of rolling in initial grooves

Physical modelling of the hot rolling of Z-section sheet piles in two initial grooves was realized with application of laboratory mill [4]. The flat samples for experimental rolling were prepared from lead and S 430 GP steel grade. All specimens have rectangular shape and dimensions 18.5 x 120 x 235 mm. The scale equal 6.5 with comparison to industrial conditions have been chosen. Example results, obtained from experimental rolling, are shown in Fig. 4 and Fig. 5.

![Fig. 4. Lead (1 and 2) and steel (3) samples after rolling in groove No. 1](image)

![Fig. 5. Pieces taken from lead samples after rolling in groove No. 1 (left) and 2 (right)](image)

The realized experimental rolling showed that slabs with rectangular cross section can be used with success as the incoming material for Z-section rolling. During first passes instead of thickness reduction the bending of the rolling stock prevails. The ends distortion were typical in sizes and forms, Fig. 4. As well as the groove filling was symmetrical and on proper level, Fig. 5. All these investigations were the basis to the planning of further research e.g. grooves design and parameters of Z-section sheet pile rolling.

3. COMPUTER AIDED PROCESS DESIGN

The complexity of phenomena taking place in hot rolling od sheet pile creates a wide range of possibilities of controlling process parameters and groove filling. However, the principal factor is the ensuring of symmetrical groove filling and controlling the level of the rolling forces, both vertical and axial. Numerical methods were used to help a proper engineering of hot sheet pile rolling. The commercial computer program 3D (Abaqus/Explicit) has been applied, Fig. 6. All passes were calculated several times until accurate profile have been obtained with the rolling forces below admissible values. Ten Z-section grooves have been assumed in calculation and the beam blank from continuous casting as the incoming material, Fig. 2. The results of calculations contribute also to better understanding of flow pattern of a material in the roll grooves, as well as the distributions of temperature, stresses and strains in the material being deformed.
Apart from that, the computer analysis provides useful information for grooves design and their location in the roll assemblies. **Fig. 7** shows the final stage of grooves design and also their filling with rolled stock. For Z-section sheet pile rolling at least ten grooves and 17 passes have to be applied to obtain expected final shape with rolling forces below admissible values.

**Fig. 7.** Example results of computer simulation of Z-section rolling: a) material filling of the groove No. 2, pass No. 4, b) material filling of the groove No. 3, pass No. 11, c) material filling of the groove No. 6, pass No. 14, d) material filling of the groove No. 10, pass No. 17 (final)
CONCLUSIONS

Industrial process of Z-section sheet rolling is very difficult and its complexity is high. Usually it requires time consuming calculations and expensive industrial trials. The results of the computer analysis provide useful data for the designing of rolling of Z-section or adjusting elaborated (or existing) roll pass design to meet very high product requirements. The obtained results also allow for formulating the more general conclusions:

1) Industrial process of Z-section sheet rolling belongs to one of the most difficult processes among long products rolling.

2) As the incoming material for these product rolling both slabs and beam blanks from continuous casting can be used.

3) The shape without axis of symmetry and high width (600 or 700 mm) of Z type sheet piles will cause during rolling very high rolling forces, both vertical and axial. Especially, the axial forces are very dangerous for rolling stands.

4) The rolling process of these sheet piles requires at least ten section grooves and 17 – 19 passes to obtain the final shape with rolling forces in safe range.

5) Computer aided roll pass design allowed for obtaining final shape of product with proper interlocks on both sides of the profile. It also enabled to place grooves in the right ways in the roll assemblies for avoiding stock twisting and/or bending at the roll exit.

6) Complexity of Z-section sheet rolling requires time consuming and expensive industrial trials before production. Computer simulation will keep to minimum the most of disadvantages of industrial trials.

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LITERATURE


