The article deals with the analysis of influence of variability of mechanical properties of thin steel sheets Zinkohal 300, thickness 1 mm and Kohal 200, thickness 1 mm to forming process. Mechanical properties and the quality of sheet surface have a considerable impact on its technological formability. The stability of the formability process requires as small variability of mechanical properties values as possible. Therefore, this article focuses on evaluation of the quality indicators variability of thin steel sheets of various grades for various directions with respect to the rolling direction using the statistical methods and computer technology.

Key words: Thin Steel Sheet, Variability of Mechanical Properties Values, Shewhart Control Chart

EXPERIMENTAL MATERIALS AND METHODS

The experimental research utilized the thin steel sheet 1 mm thick Zinkohal 300 and 1 mm thick Kohal 200. Chemical composition of the material is given in tab. 1.

<table>
<thead>
<tr>
<th>Sheet</th>
<th>C [%]</th>
<th>Mn [%]</th>
<th>Si [%]</th>
<th>P [%]</th>
<th>S [%]</th>
<th>Al [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinkohal 300 1mm</td>
<td>0.07</td>
<td>0.2</td>
<td>0.01</td>
<td>0.013</td>
<td>0.013</td>
<td>0.047</td>
</tr>
<tr>
<td>Kohal 200 1mm</td>
<td>0.083</td>
<td>0.332</td>
<td>0.005</td>
<td>0.009</td>
<td>0.017</td>
<td>0.043</td>
</tr>
</tbody>
</table>

Values of the mechanical properties gained from the uniaxial tensile test

The uniaxial tensile test made in compliance with STN EN 10002-1+AC1 on the test samples prepared pursuant to STN 42 0321 produced the following data: yield of point $R_{p0.2}$, tensile strength $R_m$, elongation $A_80$, strain hardening exponent $n$ and normal anisotropy coefficient $r$ (tab. 2). Samples were taken in the directions 0°, 45° and 90° with respect to the sheet rolling direction.

The values from the uniaxial tensile test were statistically processed using the Shewhart control charts (fig. 1 – 10). The Shewhart control chart SPC is a graph of values of the given characteristic of the subgroup compared to the subgroup serial number. The control charts help to reveal the unnatural features of variations and provide the criteria to reveal imperfections gained in statistical control.
Tab. 2 Measured and calculated average values of mechanical properties of thin sheets Zinkohal 300 thick 1mm and Kohal 200 thick 1mm from the uniaxial tensile test on the test equipment TIRAtest 2300

<table>
<thead>
<tr>
<th>Sheets</th>
<th>Rolling direction</th>
<th>$R_{p0.2}$ [MPa]</th>
<th>$R_m$ [MPa]</th>
<th>$A_80$ [%]</th>
<th>n</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinkohal 300 1mm</td>
<td>$0^\circ$</td>
<td>322</td>
<td>372</td>
<td>31.05</td>
<td>0.17</td>
<td>1.17</td>
</tr>
<tr>
<td></td>
<td>$90^\circ$</td>
<td>311</td>
<td>375</td>
<td>31.78</td>
<td>0.16</td>
<td>1.52</td>
</tr>
<tr>
<td></td>
<td>$45^\circ$</td>
<td>305</td>
<td>383</td>
<td>27.87</td>
<td>0.15</td>
<td>1.00</td>
</tr>
<tr>
<td>$\bar{X}$</td>
<td></td>
<td>312.7</td>
<td>376.7</td>
<td>30.22</td>
<td>0.16</td>
<td>1.23</td>
</tr>
<tr>
<td>Kohal 200 1mm</td>
<td>$0^\circ$</td>
<td>167</td>
<td>308</td>
<td>43.05</td>
<td>0.22</td>
<td>1.78</td>
</tr>
<tr>
<td></td>
<td>$90^\circ$</td>
<td>170</td>
<td>304</td>
<td>42.82</td>
<td>0.22</td>
<td>2.11</td>
</tr>
<tr>
<td></td>
<td>$45^\circ$</td>
<td>176</td>
<td>320</td>
<td>38.98</td>
<td>0.22</td>
<td>1.06</td>
</tr>
<tr>
<td>$\bar{X}$</td>
<td></td>
<td>171</td>
<td>310.6</td>
<td>41.62</td>
<td>0.22</td>
<td>1.65</td>
</tr>
</tbody>
</table>

They consist of the centre line $C_p$ represented in the experimental part by the total mean value, i.e. the average value of the mean in the subgroups located in the reference value of the characteristic illustrated. The control chart has two statistically set control limits, one on each side of the centre line called the upper control limit (UCL) and lower control limit (LCL). The variability within the subgroup is used as the ratio of incidental variation. Standard deviations serve to estimate $\sigma$. This ratio $\sigma$ does not include variations from one subgroup to another one, but only the components within the subgroups [3].

**SPC diagram for 1 mm thick Zinkohal 300**

Quality indicator: Yield of point $R_{p0.2}$ ($R_p$)

Fig. 1 Shewhart control charts for the quality indicator $R_{p0.2}$ Zinkohal 300 with thickness of 1mm with the control limits: a) $C_p \pm 2\sigma$, b) $C_p \pm 3\sigma$

Quality indicator: Tensile strength $R_m$

Fig. 2 Shewhart control charts for the quality indicator $R_m$ Zinkohal 300 with thickness of 1 mm with the control limits: a) $C_p \pm 2\sigma$, b) $C_p \pm 5\sigma$
Quality indicator: Elongation $A_{80}$

Fig. 3 Shewhart control charts for the quality indicator $A_{80}$ Zinkohal 300 with thickness of 1 mm with the control limits: a) $Cp \pm 2\sigma$, b) $Cp \pm 3\sigma$

Quality indicator: Strain hardening exponent $n$

Fig. 4 Shewhart control charts for the quality indicator $n$ Zinkohal 300 with thickness of 1 mm with the control limits: a) $Cp \pm 2\sigma$, b) $Cp \pm 5\sigma$

Quality indicator: Normal anisotropy coefficient $r$

Fig. 5 Shewhart control charts for the quality indicator $r$ Zinkohal 300 with thickness of 1 mm with the control limits: a) $Cp \pm 2\sigma$, b) $Cp \pm 5\sigma$

$SPC$ diagrams for 1 mm thick Kohal 200

Quality indicator: Yield of point $R_{p0.2}$ ($R_c$)

Fig. 6 Shewhart control charts for the quality indicator $R_{p0.2}$ Kohal 200 with thickness of 1 mm with the control limits: a) $Cp \pm 2\sigma$, b) $Cp \pm 4\sigma$
Quality indicator: Tensile strength $R_m$

![Graph of $R_m$ with control limits](image)

Fig. 7 Shewhart control charts for the quality indicator $R_m$ Kohal 200 with thickness of 1 mm with the control limits: a) $C_p \pm 2\sigma$, b) $C_p \pm 5\sigma$

Quality indicator: Elongation $A_88$

![Graph of $A_88$ with control limits](image)

Fig. 8 Shewhart control charts for the quality indicator $A_88$ Kohal 200 with thickness of 1 mm with the control limits: a) $C_p \pm 2\sigma$, b) $C_p \pm 5\sigma$

Quality indicator: Strain hardening exponent $n$

![Graph of $n$ with control limits](image)

Fig. 9 Shewhart control charts for the quality indicator $n$ Kohal 200 with thickness of 1 mm with the control limits: a) $C_p \pm 2\sigma$, b) $C_p \pm 3\sigma$

Quality indicator: Normal anisotropy coefficient $r$

![Graph of $r$ with control limits](image)

Fig. 10 Shewhart control charts for the quality indicator $r$ Kohal 200 with thickness of 1 mm with the control limits: a) $C_p \pm 2\sigma$, b) $C_p \pm 5\sigma
CONCLUSION

The experimental part researched the thin steel sheets of 1 mm thick Zinkohal 300 and Kohal 200. The values of sheet properties measured were processed using the mathematical models of the statistics described and the variability of these values was expressed using Shewhart control charts. The purpose of the manufacturing process statistical control is to assist in attaining and maintaining the production process at an acceptable and stable level. The process is statistically well-handled and all the values in the 0°, 90°, and 45° directions in relation to the sheet rolling direction are within the tolerance range with the control limits: \( Cp \pm 2 \sigma \). - values of the quality indicator are characterised by small variability, \( Cp \pm 3 \sigma \) - values of the quality indicator are characterised by medium variability of values, \( Cp \pm 4 \sigma \) - values of the quality indicator are characterised by large variability of values and \( Cp \pm 5 \sigma \) - values of the quality indicator are characterised by very large variability of values. In order to attain a well-handled process and all values in various 0°, 90°, and 45° directions with respect to the sheet rolling direction within the tolerance range, the tolerance range had to be extended up to the control limits \( Cp \pm 5 \sigma \). In case of some quality indicators of the sheets examined, the extension of the tolerance range was not sufficient to get them into the tolerance range owing to too large variability of values.

Based on the experiments made, the following conclusions can be drawn:

The sheet Zinkohal 300 with thickness of 1 mm shows medium variability of values for the yield of point \( Rp_{0,2} \) in various directions in relation to the sheet rolling direction, whereas the values of this quality indicator are within the tolerance range with the control limits \( Cp \pm 3 \sigma \).

The second thin steel sheet is just the opposite. Owing to very large variability, its values for this quality indicator are not within the tolerance range despite extension of the control limits \( Cp \pm 5 \sigma \).

Both researched sheets show very large variability of values for the tensile strength \( Rm \). The values for this quality indicator are not within the tolerance range with the control limits \( Cp \pm 5 \sigma \).

The values \( A80 \) of Zinkohal 300 sheets 1 mm thick are within the tolerance range with the control limits \( Cp \pm 3 \sigma \). The second examined sheet shows very high variability of values. Despite extension of the control limits \( Cp \pm 5 \sigma \), the values of this quality indicator are not within the tolerance range.

1 mm thick Zinkohal 300 shows very large variability of values of the strain hardening exponent \( n \) in the 0°, 90° and 45° directions in relation to the sheet rolling direction. All values are within the tolerance range with the control limits \( Cp \pm 5 \sigma \). The 1 mm thick Kohal 200 shows medium variability of values with the control limits \( Cp \pm 3 \sigma \).

Both examined sheets show large variability of values in various directions for the normal anisotropy coefficient \( r \). The sheet Zinkohal 300 with thickness of 1 mm - its values for this quality indicator are not within the tolerance range despite extension of the control limits \( Cp \pm 5 \sigma \). The 1 mm thick Kohal 200 - all values are within the tolerance range with the control limits \( Cp \pm 5 \sigma \).

The sheets examined meet the values of the mechanical properties measured as declared by the manufacturer. The problem lies in a large variability of the characteristics measured in various directions in relation to the rolling direction for both materials measured. This variability can cause problems in adjustment of press dies and the presses themselves, particularly in case of more complex die castings for which these sheets are designed. Defining the final properties and concurrent reduction in variability of individual values that characterise the sheet mechanical properties in the sheet manufacturing process can bring about elimination of the so far existing sheet spoilage rate and, at the same time, sheet properties meeting the requirements specified.

Large variability causes problems also with defining the input properties for numerical process simulation of these sheets processing by forming.

References


The authors are grateful to APVV for support of experimental work under grant APVV-0682-11 - Application of progressive tool coatings for increasing the effectiveness and productivity of forming sheets made of modern materials and the project VEGA No. 1/0872/14 - Research and optimization of drawing and joinability evaluation of high-strength steel sheets and aluminium steels.