Abstract

The paper deals with the methodology of measuring and valuating the mechanical properties of thin steel sheets. Analysis of material formability of thin corrosion-resistant sheet is made by evaluation of mechanical properties (Re, Rm, A), strain hardening exponent and fractographic analysis. In conclusion, the comparison of measured values with the values given in technical list is analyzed.

Key words:
Thin steel sheets, mechanical properties, tensile test

INTRODUCTION

Currently, due to the growth of industrial production, decline in global resources of raw materials, economic and energy crisis, and especially with the worsening state of the environment is generated pressure to improve utilization of resources, whether raw materials or energy. This trend did not avoid engineering production. This will involve requirements to reduce the consumption of construction materials, energy consumption in their production and processing.

One of the main opportunities to increase the technical and economic level of the products is to apply thin steel plates. This level can also be increased by applying steel sheets with high strength properties. Sheet, as a construction material, has the advantage of possibility of creating complex shapes, but also with sufficient strength and solid components.

The use of thin steel sheets is nowadays founding increasingly wider application possibilities. Considerable emphasis is placed on its properties, whether mechanical or material. At a time when more and more environmental protection takes into account is increasingly reaching for the materials with the least negative impact on the environment. [1] Thin anti-corrosion plates have increasingly utilization from thin sheets group in industry.

ANTI-CORROSION STEEL

In practice, it is often reached for the materials resistant to environmental factors, what increases the durability and permits longer use of the final product. Anti-corrosion materials are resistant to corrosion by spontaneous progressive disruption of the structure of the material due to chemical or electrochemical reaction of surroundings.

Anti-corrosion steel is defined according to DIN EN 10088: 2005 as an iron alloy containing at least 10.5% of chromium (Cr) and more than 1.2% of carbon (C). [1], [2]

High carbon content in the reaction with chromium forms chromium carbide and area depleted of chromium is created in the structure of stainless steel. This area isn’t then corrosion resistant. For this reason, low carbon content must be kept or stabilizing elements like titanium or niobium are used. [1], [2]

Higher Cr content and addition of other alloying elements such as nickel (Ni), molybdenum (Mo), manganese (Mn), copper (Cu) improves corrosion resistance and change of mechanical properties. [1], [2]

By default, the anti-corrosion steels are divided according to their metallurgical structure to consequent groups:

- ferritic steel,
- martensitic (hardenable) steel,
- austenitic steel,
- duplex (austenitic-ferritic) steel,
- dispersion strengthened steel. [1], [3]

Each group consists of several classes defined by their composition. These are defined in European standards within the specified range and in all required properties. Tensile curve of these steels is shown in Figure 1.
Sheets from stainless materials are therefore requested article, not only for their possible broad application, but also for their material properties.

To determining factors of these steels of all types can be considered:

- mechanical properties at normal and elevated temperatures,
- fracture toughness,
- position of the transition temperature,
- physical properties by prolonged exposure to operating temperature,
- structural stability that ensures the resistance to embrittlement, cracking and spreading,
- resistance against all kinds of corrosion.

When selecting a suitable anticorrosive material, it is necessary to observe to its material and mechanical properties. Basic assessment of the compressibility of the steel plates is carried out using characteristic values of the basic sheets tests.

Based on the results of these tests it is possible to create a clear understanding of material properties and its possible use in practice. Great use of these sheets is found in the engineering and nuclear industry, food industry, by manufacturing of sanitary equipment, household products and so on. [5]

EXPERIMENTAL WORK

1. THE MATERIAL AND TEST METHODS

For the experiments thin anti-corrosion sheet type EN 1.4016-X6Cr17 of thickness 0.40 mm were used.

The task of tests was to determine the material properties and for this purpose were proposed following tests:

- analysis of chemical composition of the test material,
- tensile test according to STN 10002 - 1,
- macroscopic analysis – fractography of fracture.

Type X6Cr17 is low-carbon plain chromium steel. It has good corrosion resistance in mildly corrosive environments. In the annealed condition, X6Cr17 stainless steel is ductile, does not harden excessively during cold work and can be formed using a large variety of roll forming operations as well as the more common drawing and bending processes. Thanks to high content of Cr is resistant to water, water vapor and liquids, which are not significantly more aggressive than water.

This steel is suitable for the production of tanks, products for the food industry, the application is in healthcare, for household and kitchen appliances, public health engineering, but also in many other applications and industries. [6], [7]

Chemical and physical properties of the tested materials were in accordance with EN 10088 and listed in Table 1 and Table 2. Identification of tested material in accordance with the standards is shown in Table 3.

Samples for testing were prepared from strips according to EN 10002-1 with dimensions $a_0 = 0.4$ mm $b_0 = 12.5$ mm a $l_0 = 50$ mm, from four melts labeled T1, T2, T3 and T4.

2. ANALYSIS OF CHEMICAL COMPOSITION OF TESTED MATERIALS

<p>| Chemical Composition (in weight %) |</p>
<table>
<thead>
<tr>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P max</th>
<th>S</th>
<th>N</th>
<th>Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤0.08</td>
<td>≤1.00</td>
<td>≤1.00</td>
<td>0.04</td>
<td>≤0.015</td>
<td>-</td>
<td>16.00 - 18.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Form of product</th>
<th>Thickness max. [mm]</th>
<th>Yield Strength $R_{P0.2}$ [MPa]</th>
<th>Tensile Strength $R_m$ [MPa]</th>
<th>Elongation $A_{80}$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold-rolled sheets</td>
<td>6</td>
<td>260 to 280</td>
<td>450 to 600</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mat. No.</th>
<th>DIN</th>
<th>EN</th>
<th>AISI</th>
<th>Brand Name</th>
<th>Ravne No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4016</td>
<td>X6Cr17</td>
<td>X6Cr17</td>
<td>430</td>
<td>PK336</td>
<td>336</td>
</tr>
</tbody>
</table>
Chemical analysis was performed by spectrometer Belec Compact Port. Preparation of

Table 4  The major chemical components of tested materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Chemical analysis in [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fe</td>
</tr>
<tr>
<td>T1</td>
<td>82.78</td>
</tr>
<tr>
<td>T2</td>
<td>82.63</td>
</tr>
<tr>
<td>T3</td>
<td>82.64</td>
</tr>
<tr>
<td>T4</td>
<td>82.52</td>
</tr>
</tbody>
</table>

Table 5  The accompanying chemical elements of tested materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Cu</th>
<th>Al</th>
<th>Mo</th>
<th>Ni</th>
<th>V</th>
<th>Ti</th>
<th>Nb</th>
<th>Co</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>0.063</td>
<td>0.012</td>
<td>0.044</td>
<td>0.187</td>
<td>0.079</td>
<td>0.003</td>
<td>0.039</td>
<td>0.049</td>
<td>0.01</td>
</tr>
<tr>
<td>T2</td>
<td>0.049</td>
<td>0.012</td>
<td>0.045</td>
<td>0.16</td>
<td>0.092</td>
<td>0.003</td>
<td>0.045</td>
<td>0.05</td>
<td>0.006</td>
</tr>
<tr>
<td>T3</td>
<td>0.048</td>
<td>0.009</td>
<td>0.041</td>
<td>0.155</td>
<td>0.09</td>
<td>&lt;0.002</td>
<td>0.044</td>
<td>0.045</td>
<td>&lt;0.002</td>
</tr>
<tr>
<td>T4</td>
<td>0.051</td>
<td>0.011</td>
<td>0.044</td>
<td>0.158</td>
<td>0.093</td>
<td>&lt;0.002</td>
<td>0.049</td>
<td>0.055</td>
<td>0.014</td>
</tr>
</tbody>
</table>

3. TENSILE TEST

Uniaxial tensile test is a basic test to determine the mechanical properties of materials. The tensile test was carried out on machine TIRAtest 2300 with a record of the test using software for evaluation of material properties. For tests, flat samples were used according to EN 10002-1 with L₀ = 50 mm. From each material were tested 5 samples in the rolling direction (||) and 5 samples from direction perpendicular to the rolling direction (⊥). Basic characteristics of the material - Rₚ₀,₂, Rₘ, A₅₀ were than evaluated.

By this test was also the strain hardening exponent n was evaluated, which is used as the criterion for assessing the compressibility at processes of cold plastic deformation (deep drawing, bending, etc.). With the increasing value of the strain hardening exponent, the suitability for cold plastic deformation is increasing.

The results of mechanical tests (average values of Rₘ, Rₚ₀,₂, A₅₀, n) are listed in Table 6.

Table 6  Directional values of mechanical properties of tested sheets

<table>
<thead>
<tr>
<th>Material</th>
<th>Rₚ₀,₂ [MPa]</th>
<th>Rₘ [MPa]</th>
<th>A₅₀ [%]</th>
<th>n [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>317</td>
<td>322</td>
<td>514</td>
<td>511</td>
</tr>
<tr>
<td>T2</td>
<td>311</td>
<td>298</td>
<td>499</td>
<td>491</td>
</tr>
<tr>
<td>T3</td>
<td>306</td>
<td>334</td>
<td>490</td>
<td>499</td>
</tr>
<tr>
<td>T4</td>
<td>307</td>
<td>349</td>
<td>494</td>
<td>501</td>
</tr>
</tbody>
</table>

Tensile curve of selected samples of test materials - material T1 with significant material yield strength and T3 without significant yield stress is shown in Figure 3 and Figure 4.
Violations of selected samples are shown in Figure 5 and were occurred in the measured field. The localization of deformation leads to violation of the samples in different locations with different shapes of cracks.

In this paper, properties of anticorrosion material were investigated supplied from the four melts and determined its suitability for deep drawing. Results of tests showed that:

- By chemical analysis it has been found that melt T1 has by 64% higher and melt T2 48% higher content of C than that found by EN 10088 for steel grade 1.4016. This led to higher strength of material at tensile test. Next, the presence of other alloying elements (Table 5) was found, which also affect the technical properties of the test material. Melt T3 and melt T4 corresponds to the chemical composition of stainless steel type EN 1.4016.

- At samples was observed, that plastic deformation occurred at certain locations. After localization of deformation it leads to breach at samples in different locations with similar shapes of cracks. Average values of mechanical properties of tested materials were evaluated from the process of tensile tests. All tested samples showed higher yield strength $R_{p0.2}$ - e.g. T4 material in the direction $\perp$ to the rolling direction showed measured value $R_{p0.2}$ increased up to 69 MPa more as specified in EN 10088 for steel grade EN 1.4016. At materials T3 and T4 in the direction $\perp$ to the rolling direction dominated large margins, for example at T3 material was measured $R_{p0.2}$ range of values between 320 to 380 MPa (Fig.6). Higher elongation $A_50$ by each melt with a large range of values was also found. For example, at material T3 in the rolling direction was elongation higher by 13.5%. Also all materials had very wide range of measured values. In particular, T3 material in
the rolling direction had measured values in range between 26.8 to 47.3%. The values of tensile strength and strain hardening coefficient $n$ at all melts corresponded to the values from material list.

- The observation of fracture surfaces of the tested material was classified in terms of ductile fracture, which arises by cavity mechanism. The result of ductile fracture is pin morphology of fracture surface.

We can conclude, that the measured values of tested material type EN 1.4016 marked T1, T2, T3 and T4 are higher in comparison with standard material. Materials are suitable for forming such as deep-drawing or bending.

CONCLUSION

The increase of population, development of industry and evolving technologies, it all affects the right choice of material, both in terms of price, demand, availability, workability and many other factors. Anti-corrosion steel has a relatively high content of expensive alloying elements and also require energy-intensive production methods, so its use must be rational and economical. For right choice of steel is therefore imperative thorough knowledge of material properties in relation to their conditions of use. The optimal choice of steel for tough conditions in hostile environments, particularly in new technologies in the chemical and food industry, requires a deeper knowledge or experimental verification of model conditions close to the workload.

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REFERENCES