ANISOTROPY OF THE MECHANICAL PROPERTIES OF HOT ROLLED STEEL COILS FOR WELDED PIPES

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Abstract: Hot rolled steel coils, as a result of the history of production, respectively processing, shows anisotropy of the mechanical properties, i.e. different mechanical properties in different direction. Therefore, the mechanical properties of hot rolled steel coils should be known in advance, respectively prior to its use as raw material for the production of various final products, particularly for spiral and longitudinal welded steel pipes, where mechanical anisotropy of hot rolled steel coils even more appears during the formation of hot rolled coils into the pipe. Mechanical testing of the hot rolled steel coils in transversal (T) and longitudinal (L) direction related to the rolling, were conducted.

The aim of this paper is to investigate anisotropy of the mechanical properties of the hot rolled steel (S355 EN 10025:2004) coils, used for the production of spiral and longitudinal welded steel pipes.

Keywords: ANISOTROPY, MECHANICAL PROPERTIES, STEEL COILS, WELDED PIPES.

1. Introduction

Rolling is one of the most important bulk plastic deformation processing of metals, passing between rolls, that rotate in opposite direction, where the raw material is deformed by compressive force applied by the rolls, (Fig. 1). Mostly, rolling is done at high temperature, above the recrystallization temperature and called hot rolling [1, 2].

Deformation during the rolling process causes significant change of the microstructure in terms of size of crystal grains, and in their orientation view in certain directions, depending on the direction and intensity of deformation. Microstructure evolution processes in this case, during and after hot rolling, (Fig. 3) are key factors for mechanical properties of hot rolled coils [3].

During deformation, crystal grains rotate as well as elongate, causing certain crystallographic directions and planes to become aligned with the direction in which stress is applied. Consequently, preferred orientations or textures develop and cause anisotropic behavior. The properties of a rolled sheet or plate depend on the direction in which the property is measured [4]. In processes such as rolling, grains become oriented in a preferred crystallographic direction and plane, giving a sheet texture. The properties of a rolled sheet or plate depend on the direction in which the property is measured [4].

A typical microstructure in a hot rolled low alloy steel coils is illustrated in (Fig. 4). There are planar patches of ferrite and pearlitic bands parallel to the rolling plane, or banding oriented microstructure in the longitudinal (L) and transversal (T) direction [5]. Microstructural banding is more pronounced in the rolling direction (longitudinal-L) than in the transverse direction (transversal-T).

This ferrite/pearlitic banding microstructure is responsible for mechanical properties of hot rolled coils used for spiral and longitudinal welded steel pipes.
Preferred orientation of the microstructure is known as deformation texture [6, 7, 8], while in this specific case it is called the rolling texture. As a result of this kind of microstructure orientation (rolling texture) it comes to:

- changes in mechanical properties,
- changes in optical properties,
- changes in magnetic properties,
- changes in thermal properties,
- changes in electrical properties,
- changes in resistance to corrosion, etc.

The phenomenon of occurrence of different properties in different directions is known as anisotropy.

Anisotropy derives from the Greek words: *aniso*, which means change (difference) and *tropos*, which means direction, so different properties in different directions [8]. The concept of anisotropy is very important, because it reflects the properties of the material, respectively the part depending on the direction. In case of rolling, high intense textures are formed in the transversal (T) and longitudinal (L) direction of rolling, which may lead to significantly different mechanical properties.

The mechanical properties of hot rolled steel coils like resistance to deformation (strength) and ability to deformation (ductility), are in correlation with the metallurgical properties like microstructure, grain size, etc. [9].

It is worth mentioning that except in rare cases where it can show beneficial effect, anisotropy of the mechanical properties always shows harmful effects. Although its full elimination is very difficult, we should follow and analyze the intensity of the harmful effect of anisotropy of mechanical properties.

At hot and cold rolled products there comes to the appearance of anisotropy of mechanical properties, respectively the appearance of different mechanical properties in different directions.

Taking this into consideration, this paper takes a look at the anisotropy of mechanical properties of rolled coils, used for the manufacturing of spiral and longitudinal welded steel pipes.

2. **Experimental procedure**

2.1. **Material**

In this paper it is reviewed the effect of anisotropy of mechanical properties of hot-rolled coils from steel S355 according to EN 10027:2003, (Fig. 5) which is used as raw material for the manufacturing of welded steel pipes with spiral and longitudinal seam. This steel is produced in the shape of hot-rolled coils.

The chemical composition and mechanical properties of hot rolled steel coils S355 (EN 10027:2003), according to the manufacturer’s Certificate are presented in Tab. 1, respectively 2.

<table>
<thead>
<tr>
<th>Table 1: Chemical composition of used steel coils S355</th>
</tr>
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<tbody>
<tr>
<td>Steel coils</td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>S355</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2: Mechanical properties of used steel coils S355</th>
</tr>
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<tbody>
<tr>
<td>Steel coils</td>
</tr>
<tr>
<td>MPa</td>
</tr>
<tr>
<td>S355</td>
</tr>
</tbody>
</table>

2.2. **Mechanical testing**

With the aim of monitoring the anisotropy of mechanical properties of the hot-rolled coils, the following tests were conducted:

2.2.1. Tensile testing were conducted in order to determine yield strength (Re), ultimate tensile strength (Rm), ratio (Re/Rm) and elongation (A).

2.2.2. Impact toughness testing were conducted to determine Charpy-V notch impact toughness (Kv), at temperature (-20°C).

2.2.3. Hardness testing were conducted to determine Vickers hardness (HV30/15).

To conduct all these tests, samples were taken from the hot-rolled coils, according to the scheme given in (Fig. 6).
3. Results and discussion

The tensile testing was conducted in the universal testing machine, MOHR-FEDERHAFF-LOSENHAUSEN and the obtained results are presented in Tab. 3.

Table 3: Results of tensile testing

<table>
<thead>
<tr>
<th>Samples</th>
<th>Transversal direction - T</th>
<th>Longitudinal direction - L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Re</td>
<td>Rm</td>
</tr>
<tr>
<td></td>
<td>MPa</td>
<td>%</td>
</tr>
<tr>
<td>S1.</td>
<td>442</td>
<td>540</td>
</tr>
<tr>
<td>S2.</td>
<td>405</td>
<td>517</td>
</tr>
<tr>
<td>S3.</td>
<td>430</td>
<td>540</td>
</tr>
<tr>
<td>Average</td>
<td>426</td>
<td>532</td>
</tr>
</tbody>
</table>

The impact toughness testing (ISO-V-5) was conducted in the Charpy pendulum, MOHR-FEDERHAFF-LOSENHAUSEN, at temperature (-20°C) and the obtained results are presented in (Fig. 7).

The hardness testing, respectively Vickers hardness (HV30/15) was conducted in the hardness tester Shimadzu.

Fig. 7 Charpy impact toughness

Fig. 8 Positions of hardness measure (HV30/15)

The results from hardness measure (HV30/15) are presented in (Fig. 9).

Fig. 9 Hardness values (HV30/15)
The average value of the yield strength in the transversal direction \( (R_{yT} = 426 \text{ MPa}) \) is bigger than the average value of the yield strength in the longitudinal direction \( (R_{yL} = 396 \text{ MPa}) \), for 7.57\%, while the ultimate tensile strength in the transversal direction \( (R_{mT} = 532 \text{ MPa}) \) is also bigger than the ultimate tensile strength in the longitudinal direction \( (R_{mL} = 520 \text{ MPa}) \), for 2.30\%.

Impact toughness in the transversal direction \( (K_{vT} = 52.4 \text{ J/cm}^2) \) is smaller than impact toughness in the longitudinal direction \( (K_{vL} = 166 \text{ J/cm}^2) \), for 3.16 times and this is the biggest difference which appears at the ho-rolled coils and it must be taken into account when using the hot-rolled coils as semi-product, respectively as raw material for the production of finished products in general and for the production of spiral and longitudinal welded steel pipes in particular, used for line pipes, tubing, casing and for other applications.

The distribution of hardness values \( (HV30/15) \) in the longitudinal \( (L) \), transversal \( (T) \) and surface layer shows slightly difference \( (\Delta HV = HV_{\text{max}} - HV_{\text{min}} = 188 - 165 = 23HV) \). Maximum hardness, (Fig. 9) is measured in the surface layer-S \( (HV_{\text{max}} = 188) \), while minimum hardness is measured in the longitudinal-L \( (HV_{\text{min}} = 165) \).

4. Conclusion

Based on the literature review of relevant field and based on the experimental results, it can be concluded that:

Anisotropy of mechanical properties of the hot-rolled coils is emphasized both in terms of the resistance to deformation (yield strength\( \text{-} Re \), ultimate tensile strength\( \text{-} Rm \), ratio\( \text{-} Re/Rm \), hardness\( \text{-} HV \)) and also in terms of the ability to deformation (elongation\( \text{-} A \)), but in this case it is not very pronounced and can be neglected.

Anisotropy of impact toughness \( (Kv) \) of hot-rolled coils is significantly emphasized, so in this case impact toughness in longitudinal direction\( -L \) is nearly three times \( (3X) \) greater than the impact toughness in the transversal direction\( -T \). This is the biggest difference between these two directions of hot rolled coils and necessarily must be considered when using the hot-rolled coils for manufacturing of spiral and longitudinal welded steel pipes.

5. References