Effect of quenching techniques on the mechanical properties of low carbon structural steel

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Abstract

The paper presents the results of the impact of incomplete quenching technique on the mechanical properties of low carbon structural steel. Significant influence of the heating method to the $\alpha + \gamma$ field was observed on the strength and plasticity after hardening process. The best combination of mechanical properties was obtained for the 3th technique consisting of pre-heating the material to the austenite field, next cooling to the appropriate temperature in the $\alpha + \gamma$ and hardening from that dual phase region. The high level of toughness with relatively high strength were observed, compared to the properties obtained for the two other ways to quench annealing (incomplete hardening).

Keywords: heat treatment, mechanical properties, steel DP, incomplete hardening, plasticity

1. Introduction

High-strength welded steels are the main group of construction materials for highly loaded and accountability of large structural components and machine parts. Because of the specific properties that type of materials could be used for the elements transferring static and dynamic load. They are used in normalized state and after suitable heat or thermo plastic treatment increasing mechanical properties without modifying the chemical composition of expensive alloy additions. Proper weldability of steel forces reduce the carbon content to below 0.2%. Now there is a strong tendency to high reduce C content to less than 0.01% [1]. Therefore it is necessary to use other methods for increase the mechanical (strength) properties, which include the use of microalloying in the form of Nb, Ti, V, to control the grain size and the austenite recrystallization temperature, the use of controlled thermo-plastic treatment and obtain low-temperature products of austenite transformation. The next mechanism, to allow the control the mechanical properties of low carbon steels of a wide range, is the hardening technique from inter critical the $\alpha + \gamma$ region, resulting in a two-phase structure type of DP (Dual Phase) ferritic-martensitic or ferritic-bainitic, depending on the applied cooling rate. These DP steels are widely used in the automotive industry for use as deep-drawing sheets. An additional advantage of a DP steels is an opportunity to design their structure and properties directly in the process of controlled rolling combined with accelerated cooling [2].

The studies on search of high strength steel, so called AHSS (advanced high Strength Steels), were undertaken in cooperation motor industry with steel suppliers. Results obtained under the program ULSAB-AVC (Ultra Light Steel Auto Body - Advanced Concepts Vehicle) shows that use of 85% of the steel type of AHSS reduces the weight of body of a car by about 25% without increasing production costs. The vast majority of the components of the car covering is designed with the use of dual phase steel.
Because of their specific microstructural features, ferritic-martensitic steel type DP is an attractive combination of strength and ductility. [3]

2. Methods and results

Low alloy structural steel with chemical composition given in Table 1 and the properties showed in Table 2 was carried out a preliminary research.

Table 1.
Chemical composition of investigated steel

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>S</th>
<th>P</th>
<th>Cr</th>
<th>Ni</th>
<th>Cu</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contents [%]</td>
<td>0.15</td>
<td>1.27</td>
<td>0.3</td>
<td>0.02</td>
<td>0.014</td>
<td>0.16</td>
<td>0.14</td>
<td>0.3</td>
<td>0.026</td>
</tr>
</tbody>
</table>

Table 2.
Properties of the investigated steel in delivered state

<table>
<thead>
<tr>
<th>Rm [MPa]</th>
<th>Re [MPa]</th>
<th>A [%]</th>
<th>HV</th>
<th>KCU [J/cm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>545</td>
<td>335</td>
<td>34</td>
<td>187</td>
<td>154</td>
</tr>
</tbody>
</table>

The following diagrams of heat treatment of the material were selected based on the literature data. First the material was normalized at a temperature of 870°C and subsequently, depending on the treatment of:

1. quenching from the temperature of two-phase range and 900°C, followed by high tempering of samples
2. quenching from 900°C temperature, quenching from the temperature of two-phase range, followed by high tempering of some samples
3. quenching from 900°C temperature, cooling to the two-phase range and quenching, followed by high tempering of some samples

Investigations of mechanical properties in order to determine the heat treatment, whereby you can get the best combination of mechanical properties and plasticity. Therefore, a method for Vickers hardness measurements on the basis of the PN-EN ISO 6507-1:2007 and toughness on samples with dimensions of 10 x 10 x 55 mm with 2 mm notch U-shaped on the basis of the PN-EN 10045-1:1994. It was also carried out static tensile test at room temperature on samples of diameter 5 mm and a length of 25 mm measurement base, according to the standard EN 10002-1:2001. Tests conducted on a hydraulic testing machine of EU-20. The study was performed for each type of heat treatment. For easier interpretation of the results of these tests are presented in graphical form.
Based on the results of toughness, it was found that the highest toughness was obtained for the material after hardening and high tempering, but materials after heat treatment number 1 were characterized by higher toughness of about 100 J/cm² from the other two treatments (Fig. 4 and 5). Along with raising annealing temperature increases slightly toughening toughness of the material. The exception here is the heat treatment number 2, where both samples quenched and tempered and high tempering temperatures in the upper α + γ toughness decreases slightly.

Hardness tests indicate a significant effect of temperature inter critical hardening and heat treatment on material properties. Hardness, for quenched materials, is obtained at the level of 230-460 HV (Fig. 6) and for materials quenched and high tempered from about 180 to 200-230 HV (Fig. 7) for each method of heat treatment. The increase of annealing temperature inter critical increases hardness of the material. The highest hardness is obtained for the heat treatment number 1.
As a result of static tensile tests specified tensile strength after heat treatments carried out. Hardened material was characterized by very high values of tensile strength, which, for the treatment of number 3 ranged from about 1000 to 1500 MPa (Fig. 8). After quenching and tempering the high value of maximum transmissible strain was reduced and ranged between about 580 and 650 MPa (Fig. 9).

As a result of static tensile tests specified level of yield for the test materials. With the increase of annealing temperature intercritical showed an increase of flow stress. For materials toughened its value changes very broad and ranges from about 440 to 1090 MPa (Fig. 10), in the case of the samples after hardening and high tempering process, the additional value shall be equal to from about 370 to 580 MPa (Fig. 11). For both samples as well as hardened and tempered high tempering get the best property in the case of heat treatment number 3.
The total elongation of samples was also determined. With the increase of annealing temperature inter critical we see the decline in its value. For samples quenched level of elongation is within the range of about 7 to 20%, with the highest value is achieved for the heat treatment number 3 (Fig. 12). As a result of high temper elongation values were little changed, with the exception of heat number 1, where the percentages more than doubled.

It is estimated the relative narrowness of the samples from the static tensile test. For samples quenched level of elongation increased with annealing temperature minter critical and ranged from approximately 28 to 54% (Fig. 14), while for samples quenched and tempering the differences in the level of necking due to a heat treatment were minor and were at the level of approximately 72 to 77% (Fig. 15).

3. Conclusions

On the basis of obtained results it was found that the best combination of mechanical properties obtained for the heat treatment no. 3, consisting of quenched from 900°C temperature with the following cooling of the temperature of two-phase and quenching in water from this temperature. In addition, the material was subjected to a process of high temperature. With this heat treatment has been some increase in hardness in the case of...
toughened and high tempered and more than doubled in the case of only tempered. The heat treatment process contributed to reduce the toughness of the material only tempered and almost double the growth for the samples quenched and high tempering. There was also a high value of yield stress and tensile strength, which for samples quenched from temperatures 800 - 820°C are about three times higher than it is delivered. In the case of tempered and high tempered observed a smaller increase in tensile strength and yield. The increase in strength properties contributed to the slight decrease of relative elongation. The material is also distinguished by a high level of necking.

References