HEAT TREATMENT AND MECHANICAL PROPERTIES OF HEAVY FORGINGS FROM A694–F60 STEEL

TOPLOTA OBDELAVA IN MEHANSKE LASTNOSTI TEŽKIH IZKOVKOV IZ JEKLA A694-F60

Martin Balcar¹, Jaroslav Novák¹, Libor Sochor¹, Pavel Fila¹, Ludvík Martínek¹, Jiří Bažan², Ladislav Socha², Danijela Anica Skobir Balantić³, Matjaž Godec³

¹ZDAS, a. s., Strojírenská 6, 591 71 Žďár nad Sázavou, Czech Republic
²VŠB TU Ostrava – FMML, 17. listopadu 15/2172, 708 33 Ostrava-Poruba, Czech Republic
³Institute of Metals and Technology, Lepi pot 11, 1000 Ljubljana, Slovenia
martin.balcar@zdas.cz

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The production of heavy steel forgings of micro-alloyed steels gives the possibility to obtain advantages associated with the benefit of the application of micro-alloying elements and thermomechanical treatments for improving the mechanical properties of forgings to level by sheets, strips and tubes. The paper presents the influence of quenching temperature on the mechanical properties and microstructure of F60 steel according to ASTM A694. The verification of the influence of quenching temperature contributes to an optimization of the method of micro-alloyed steel heat treatment. The steel’s microstructure and mechanical properties after quenching constitute the initial and basic criteria to achieve the required mechanical properties after a properly chosen tempering temperature.

Keywords: HSLA steel, A694 F605, quenching and tempering


Ključne besede: HSLA-jeklo, A694 F605, kaljenje in popuščanje

1 INTRODUCTION

As the requirements for the properties of structural steel are increasing, the development of the use of micro-alloying elements, even in the field of the production of forgings and castings, takes place. The production of heavy steel forgings of micro-alloyed steels does not allow the use of the advantages associated with the benefit of the application of micro-alloying elements and thermomechanical treatment known from the production of sheets, strips and tubes. The production of steel forgings involves forming and heat-treatment processes, which are significantly different than those for thin-walled products (sheets, strips, tubes).

The development and verification of F60 steel production and treatment technology according to ASTM A694 in ZDAS, Inc. conditions constituted a number of technological changes and the introduction of new process elements in the field of steel making and thermomechanical treatment. The verification of the influence of the quenching temperature on the properties and the microstructure of F60 forged steel contributes to the optimization of the HSLA steel-making technology at ZDAS, Inc.

2 EXPERIMENTAL MATERIAL

The verification of the influence of quenching temperature on the microstructure and mechanical properties of modified F60 steel according to ASTM A694 made by EOP/LF/VD technology was carried out on forged samples with dimensions 100 mm × 100 mm × 150 mm. The basic chemical composition of the steel is shown in Table 1.

<p>| Table 1: Basic chemical composition of HSLA steel F60 in mass fraction, w/% |
| Tabela 1: Osnovna kemična sestava HSLA jekla F60 v masnih deležih, w/% |</p>
<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>V</th>
<th>Al</th>
<th>Nb</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>1.08</td>
<td>0.33</td>
<td>0.003</td>
<td>0.001</td>
<td>0.16</td>
<td>0.77</td>
<td>0.27</td>
<td>0.04</td>
<td>0.027</td>
<td>0.034</td>
<td>0.0037</td>
</tr>
</tbody>
</table>

The F60 steel modified according to ASTM A694 is a typical low-carbon steel with the addition of the alloying elements, manganese, nickel and molybdenum. Moreover, the steel is micro-alloyed with vanadium, aluminium and niobium. The content of other elements is at the level of residuals.
After the forming process, the forgings were "anti-flake" annealed at a temperature of 650 °C for a period of 10 h and then normalized at a temperature of 930 °C with air cooling.

3 LABORATORY HEAT TREATMENT

The heat treatment was carried out on forged steel samples in the laboratory. The verification of the influence of the austenitization–quenching temperature ($T_A$) on the microstructure and mechanical properties was performed for the temperature range of 880 °C to 940 °C with water quenching, tempering $T_P = 620$ °C and air cooling. The sample markings and heat treatment were carried out as follows:

Sample L1: $T_A = 880$ °C/6 h/water + $T_P = 620$ °C/8 h/air
Sample L2: $T_A = 890$ °C/6 h/water + $T_P = 620$ °C/8 h/air
Sample L3: $T_A = 900$ °C/6 h/water + $T_P = 620$ °C/8 h/air
Sample L4: $T_A = 910$ °C/6 h/water + $T_P = 620$ °C/8 h/air
Sample L5: $T_A = 920$ °C/6 h/water + $T_P = 620$ °C/8 h/air
Sample L6: $T_A = 930$ °C/6 h/water + $T_P = 620$ °C/8 h/air
Sample L7: $T_A = 940$ °C/6 h/water + $T_P = 620$ °C/8 h/air

4 MECHANICAL PROPERTIES OF F60 HSLA STEEL

The samples for determining the achieved mechanical properties and to evaluate the microstructure were taken from the central zone of the forgings in the longitudinal direction. In Table 2 the requested level and attained values of the mechanical properties of individual F60 steel samples are shown.

The influence of the austenitization temperature on the change in the mechanical properties of forged, quenched and tempered F60 steel is visible from Table 2. It is obvious that the steel’s strength increases and a significant toughness drop occurs with an increase of the austenitization temperature. An austenitization temperature of over 910 °C causes the steel to become brittle.

5 MICROSTRUCTURE OF SAMPLES OF HSLA STEEL ASTM A694 F60

Like in the case of the mechanical properties, the steel microstructure was evaluated in the control zone of samples. The steel microstructure for the heat-treatment states ($T_A = (880, 900, 920, 940)$ °C) is shown in Figure 2 to 5:

After quenching and tempering, the microstructures of all the sample forgings are practically the same and it consists of ferrite, bainite, granular pearlite and sorbite. It is evident from the micrographs where the secondary grain size can be compared more easily, that the secondary grain size does not change noticeably with an increase of the quenching temperature. This is confirmed
Figure 2: Sample L1: $T_A = 880 \, ^\circ C/6 \, h/\text{water} + T_P = 620 \, ^\circ C/8 \, h/\text{air}$

Slika 2: Vzorec L1: $T_A = 880 \, ^\circ C/6 \, h/\text{voda} + T_P = 620 \, ^\circ C/8 \, h/zrak$

Figure 3: Sample L3: $T_A = 900 \, ^\circ C/6 \, h/\text{water} + T_P = 620 \, ^\circ C/8 \, h/\text{air}$

Slika 3: Vzorec L3: $T_A = 900 \, ^\circ C/6 \, h/\text{voda} + T_P = 620 \, ^\circ C/8 \, h/zrak$

Figure 4: Sample L5: $T_A = 920 \, ^\circ C/6 \, h/\text{water} + T_P = 620 \, ^\circ C/8 \, h/\text{air}$

Slika 4: Vzorec L5: $T_A = 920 \, ^\circ C/6 \, h/\text{voda} + T_P = 620 \, ^\circ C/8 \, h/zrak$

Figure 5: Sample L7: $T_A = 940 \, ^\circ C/6 \, h/\text{water} + T_P = 620 \, ^\circ C/8 \, h/\text{air}$

Slika 5: Vzorec L7: $T_A = 940 \, ^\circ C/6 \, h/\text{voda} + T_P = 620 \, ^\circ C/8 \, h/zrak$
by the results of the assessment of the austenite grain size by the oxidation method according to ASTM E 112–97 using LECO IA32 image analysis. The results of the austenitic grain-size assessment are shown in Table 3.

From the results in Table 3 it is not possible to establish the direct influence of quenching temperature on the austenite grain-size change as all the samples show a very fine grain size.

6 CONCLUSIONS

From the results of the experimental work we can see the direct influence of the quenching temperature on the mechanical properties of the F60 steel.

A slight increase of strength and a strong drop in impact value was found for an increase of the quenching temperature. The most favourable results of the mechanical properties were attained with the quenching temperatures 880 °C, 890 °C and 900 °C.

The steel microstructure after quenching and tempering is similar for all samples and consists of ferrite, bainite, granular pearlite and sorbite. The assessment of the austenite grain size by the oxidation method confirmed the grain-size uniformity, when comparing experimental samples, without any provable influence of the quenching to a temperature of 920 °C.

A further optimization of the steel’s mechanization properties and microstructure is expected after a verification of the influence of the tempering temperature. Subsequently, it will be possible to determine a complex optimized heat-treatment process for the HSLA steel ASTM A694 F60.

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