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

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

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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

Proizvodnja težkih izkovkov iz mikrolegiranih jekel omogoča, da se uporabijo prednosti mikrolegiranja in termomehanske obdelave za doseganje mehanskih lastnosti pri trakovih, ploščah in ceveh. V članku je predstavljen vpliv temperature kaljenja na mehanske lastnosti in mikrostrukturo. Preveritev vpliva temperature kaljenja je del procesa opredelitve in optimizacije metode toplotne obdelave mikrolegiranega jekla. Mikrostruktura in mehanske lastnosti po toplotni obdelavi so osnovni pogoj za doseganje predpisanih lastnosti.

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**.

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.

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/%

C	Mn	Si	P	S	Cr	Ni	Mo	V	Al	Nb	N
0.10	1.08	0.33	0.003	0.001	0.16	0.77	0.27	0.04	0.027	0.034	0.0037

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

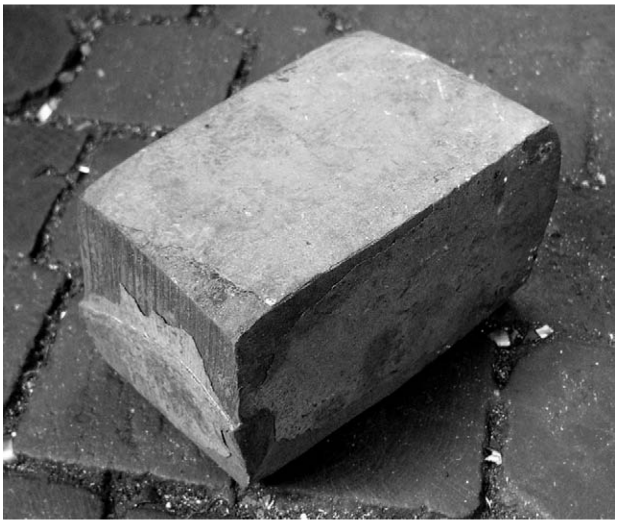

Figure 1: Forging specimen - 100 mm × 100 mm × 150 mm
Slika 1: Odkovek, 100 mm × 100 mm ×150 mm

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

Table 3: Austenitic grain size - HSLA steel F60 -ASTM E 112 – LECO IA32
Tabela 3: HSLA-jeklo F 60 - ASTM E 112 - LECO IA32

	T_A/°C	Grain size /μm
L1	880	11.3 ± 0.4
L2	890	11.2 ± 0.4
L3	900	10.7 ± 0.3
L4	910	11.3 ± 0.5
L5	920	11.4 ± 0.2
L6	930	9.4 ± 0.6
L7	940	10.3 ± 0.4

Table 2: Mechanical properties HSLA steel F60 after different austenization temperatures
Tabela 2: Mehanske lastnosti HSLA-jekla F 60 po avstenitizacij pri različnih temperaturah

	T_A/°C	R_e/MPa	R_m/MPa	A5/%	Z/%	$KV_{-46\,°C}$/J			AVG $KV_{-46\,°C}$/J
		415–565	520–760	min. 20	min. 35	ø KV min. 63			ø KV min. 63
L1	880	548	639	21.6	76.0	299	300	217	272
L2	890	550	653	22.2	75.0	255	229	286	257
L3	900	561	653	21.8	75.0	213	217	218	216
L4	910	573	667	22.2	75.0	101	214	89	135
L5	920	576	662	23.0	76.0	189	137	27	118
L6	930	576	672	22.8	74.0	124	204	238	189
L7	940	576	671	22.4	75.0	86	153	31	90

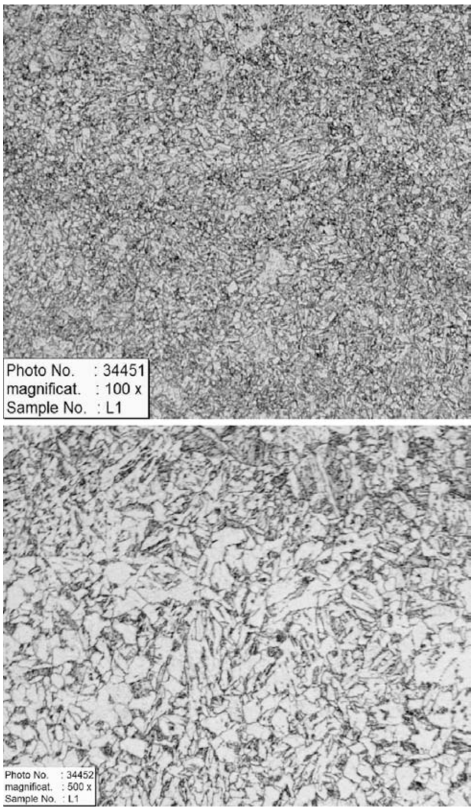

Figure 2: Sample L1: T_A = 880 °C/6 h/water + T_P = 620 °C/8 h/air
Slika 2: Vzorec L1: T_A = 880 ºC/ 6 h/ voda + T_p = 620 ºC/ 8 h/zrak

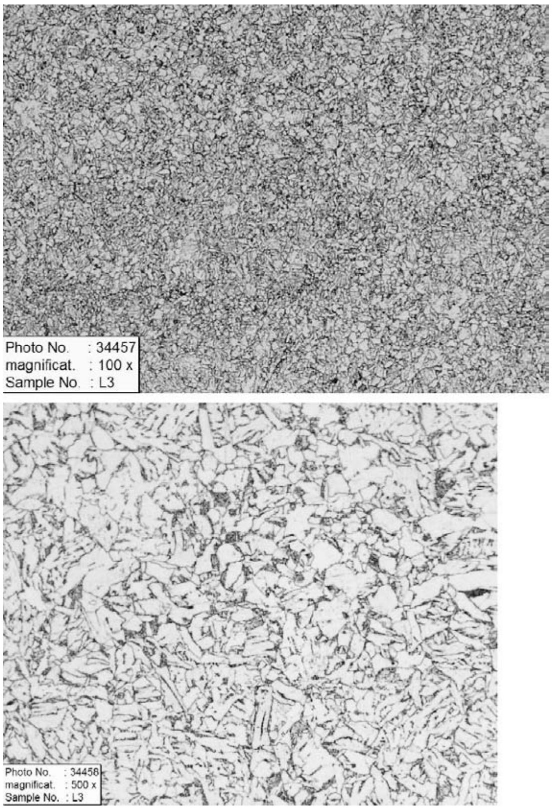

Figure 3: Sample L3: T_A = 900 °C/6 h/water + T_P = 620 °C/8 h/air
Slika 3: Vzorec L3: T_A = 900 ºC/ 6 h/ voda + T_p = 620 ºC/8 h/zrak

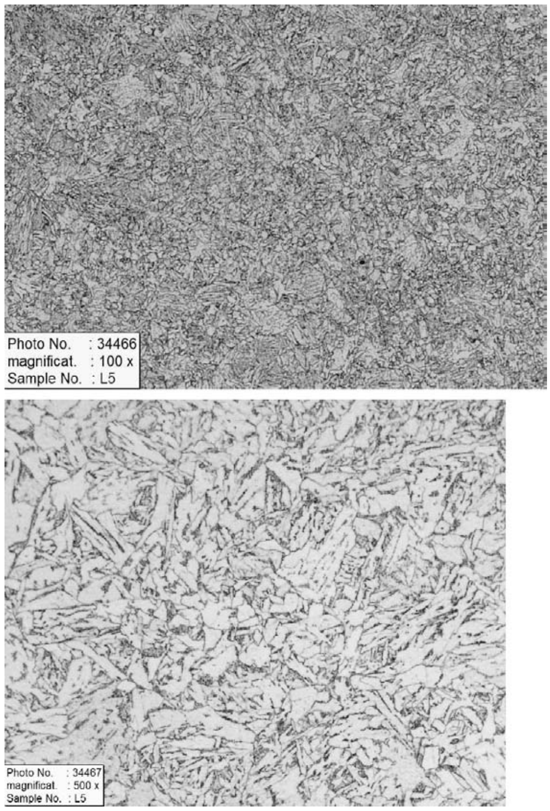

Figure 4: Sample L5: T_A = 920 °C/6 h/water + T_P = 620 °C/8 h/air
Slika 4: Vzorec L5: T_A = 920 ºC/ 6 h/ voda + T_p = 620 ºC/ 8 h/zrak

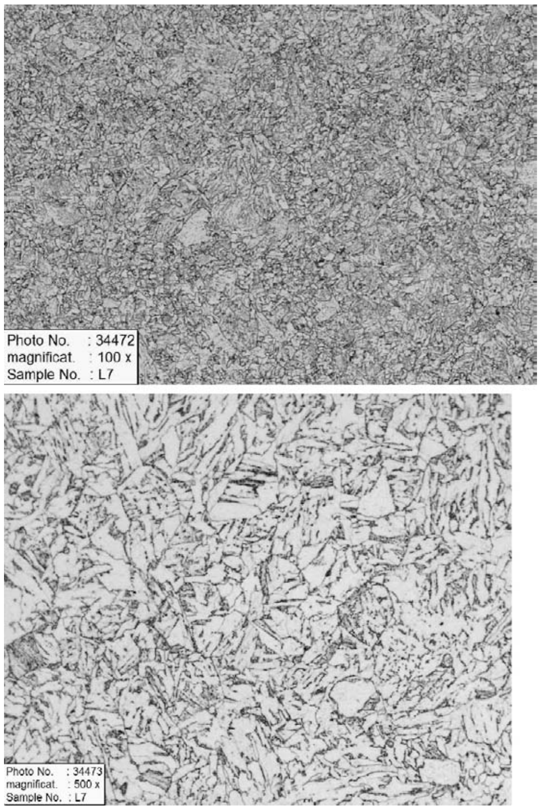

Figure 5: Sample L7: T_A = 940 °C/6 h/water + T_P = 620 °C/8 h/air
Slika 5: Vzorec L7: T_A = 940 ºC/ 6 h/ voda + T_p = 620 ºC/8 h/zrak

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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