CHARACTERISTICS OF THE MICROSTRUCTURE AND GRAIN SIZE OF S690QL STEEL IN THE HARDENED AND TEMPERED STATE

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ABSTRACT
Steel S690 QL is a high-strength quenched and tempered, fine-grained structural steel with a minimum yield strength of R_{eH} of 690 MPa and with guaranteed toughness (Charpy) for rolled plates with a thickness of 3 to 50 mm. This paper presents the examination and analysis of the microstructure and grain size results after quenching and tempering. Also, the aim of the examination is to consider the segments of the technological process and its influence on the physical and metallurgical characteristics, primarily on the microstructure and grain size, which affect the tensile characteristics and toughness at low temperatures.

1. INTRODUCTION

The high-strength steels are developed mainly to achieve the highest possible yield stress and tensile strength by reducing the load-bearing sections and the total cost of materials [1]. The steel S690 QL is a high-strength structural steel produced in accordance with the EN 10025-6 standard. It is heat treated by quenching and tempering and has good bending and welding properties. According to the mark, this is structural steel, (S) with a minimum yield strength of 690 MPa, quenched and tempered (Q), and toughness tested at low temperature (L) [2]. This steel belongs to the group of quality structural steels, so it is recommended that they have a certain content of elements for refining the microstructure as aluminium for example, especially the grain size. Standard EN 10025-6:2004+A1:2009 prescribes that the minimum soluble aluminium content should be 0.010% if the total aluminium content is 0,013%. According to the EN 10025-1 standard, if the content of niobium is 0,02%, titanium 0,02%, and vanadium 0,003%, the carbon content is limited to 0,18% for plates with a thickness of 30 mm [3].

2. STEEL S690QL

Hot-rolled plates made of HSLA steel (S690 QL) in the hardened and tempered state are used for testing. According to the standard EN 10025-6, the technical requirements for delivery prescribe the chemical composition, tensile characteristics, and 30J toughness at the temperature of -40°C in the longitudinal section, and 27 J in the cross-section. Only the toughness in cross-section in the values of 27 J is prescribed in the document „Technical data sheet Acroni“. The values of the mechanical properties for S690 QL steel plate are given in Table 1 for thicknesses greater than 3 mm and less than 50 mm. The values for the yield stress and tensile strength depend on the thickness of the plates. Because the thickness of the tested samples was 10 and 40 mm, Table 1 presented only values for this thickness.

Table 1. Mechanical properties of the steel S690 QL according to standard EN 10025-6

Yield stress R_{eH}, MPa	Tensile strength R_m, MPa	Elongation %	Toughness -40°C, J
Min. 690	770 - 940	14	30

The chemical composition, processing technology, and final heat treatment favour the formation of a fine-grained microstructure, i.e. the microstructure typical for the hardened and tempered state. The EN 10025-6:2004+A1:2009 standard does not prescribe the appearance of the microstructure, nor the grain size, for these plate thicknesses. However, a complete evaluation of the quality of the produced plates, and the examination of the microstructure and grain size are of great importance. Testing and analysis of the toughness were carried out at a temperature of - 40°C, from 10 plates of different thicknesses.

3. EXSPERIMENTAL PART

3.1 Chemical analysis

The chemical analysis of the produced melts is given in Table 2, together with the standard (according to the standard EN 10025-6) prescribed maximum content of elements.

Table 2. Chemical analysis of melts

Melt	The chemical composition, %													
	C	Si	Mn	P	S	Cr	Cu	Ni	Al	Mo	Ti	Nb	N	B
Standard Max	0.22	0.86	1.80	0.025	0.012	1.60	0.55	2.10	*	0.74	0.07	0.07	0.016	0.006
T-1	0.144	0.27	1.20	0.007	0.0005	0.34	0.24	0.208	0.074	0.19	0.017	0.024	0.0050	0.0032
T-2	0.148	0.34	1.40	0.008	0.0010	0.54	0.22	0.255	0.052	0.30	0.021	0.025	0.0061	0.0032
T-3	0.149	0.30	1.14	0.005	0.0001	0.32	0.20	0.207	0.055	0.16	0.017	0.023	0.0055	0.0032
T-4	0.148	0.27	1.13	0.005	0.0005	0.36	0.24	0.210	0.048	0.17	0.015	0.022	0.0052	0.0032
T-5	0.144	0.28	1.11	0.007	0.0005	0.31	0.25	0.197	0.080	0.18	0.015	0.023	0.0068	0.0032

**According to the standard, the aluminum content is not specified because it interacts with the presence of nitrogen*

The chemical composition of all melts is in accordance with EN 10025-6 and DIN EN 10025-1, for steel S690 QL and for the main elements, as well as for additional requirements regarding the regulation of nitrogen content and elements that translate it into stable microconstituents.

3.2 Hot rolling and heat treatment

Hot rolling was performed according to standard rolling technology. In the technological process of hot rolling, the slabs are placed in a furnace that is heated to a temperature of approx. 1300°C for one hour. In certain cases due to occasional disturbances in the technological process, that time is extended, which can certainly affect the structure and mechanical properties, especially the grain size. Also, the temperature at the end of rolling, which can vary, can have an influence on the microstructure and grain size. All the mentioned can produce certain inhomogeneities in the microstructure, especially in the properties in the longitudinal and cross-section. The heat treatment by hardening and tempering is carried out according to a standard technological procedure in accordance with the procedures carried out for HSLA structural steels, and they are aligned with the parameters that ensure the formation of a fine improved structure, which allows the prescribed tensile characteristics and toughness to be achieved at low temperatures.

Figure 1 shows ten heat-treated samples for microstructure and grain size testing. The samples are 100x200mm in size and 10mm to 40mm thick. The samples were cut from the plates produced from 5 different melts. The direction of rolling is marked with an arrow on the plates and the sample mark is written too. It is connected to the plate mark and the number of the melt from which it was produced. The aim of the examination is to consider the segments of the technological process and its influence on the physical and metallurgical characteristics, primarily on the microstructure and grain size, which affect the tensile characteristics and toughness at low temperatures.

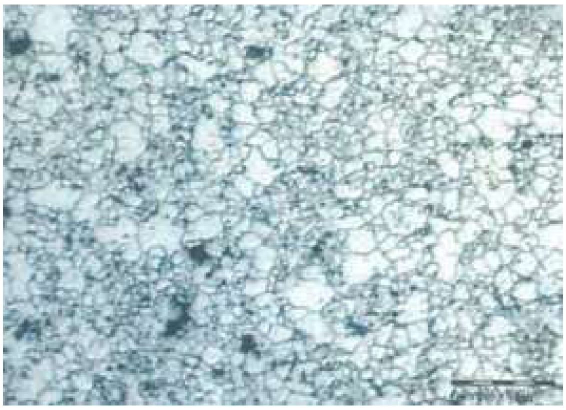
Figure 1. Samples for testing microstructure and grain size taken from melts from T-1 to T-5

3.3. Testing

3.3.1 Microstructure

Analysis of the microstructure was performed in the metallographic laboratory of the Institute „Kemal Kapetanović“ (IKK), on a longitudinal section after etching in 2% HNO_3, on an Olympus PMG 3 optical microscope according to the ASTM E 407-07 standard. The microstructure of all samples is tempered fine grain microstructure, Figure 2. The microstructure on the longitudinal section is in the form of strips, which is enhanced by the presence of elements that are prone to the formation of segregations, and the technological process of rolling itself, and certain thermal processes in the production technology, also have an influence. Reducing anisotropy in hot-rolled plates is an important metallurgical task and during production, it is attempted to make plates with as much uniformity of microstructure as possible on the longitudinal and cross-section, which is especially important for toughness at low temperatures.

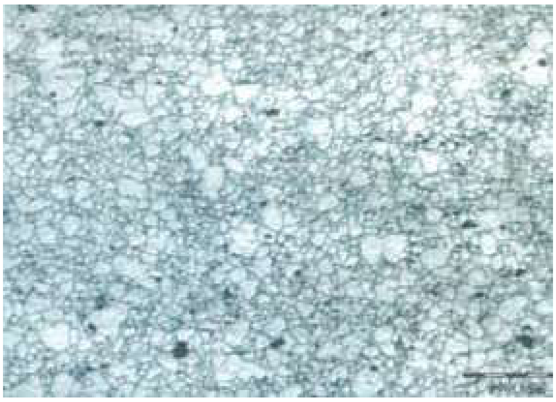
Sample 7



Place of testing

2% HNO_3
x150

Sample 8



Place of testing 2% HNO_3 x150

Figure 2. The appearance of grain size for individual melt samples

3.3.2 Grain size

The grain size was tested on the IKK according to the ASTM E 412-Plate13 standard. The results of testing the grain size and thickness of the test plates are given in Table 3 and in the diagram in Figure 3. The maximum, minimum, and average sizes are shown. Because the grain borders were not visible, the samples (before testing) were heated to the austenitization temperature of 860 °C, keep for 60 min, and cooled in water.

Table 3. The grain size of samples for steel S690 QL

Sample	Thickness D, mm	Grain size		
		Average grain size, P	Maximum grain size, D_{max}	Minimum grain size, D_{min}
1	25	7.5	6.0	10.5
2	30	7.0	5.5	9.5
3	25	7.5	5.5	10.5
4	20	7.0	5.5	10.0
5	20	7.5	5.5	9.5
6	15	7.0	5.5	10.0
7	25	7.0	5.5	9.5
8	25	7.5	5.5	9.5
9	25	7.0	5.5	9.5
10	25	7.5	5.5	10.0

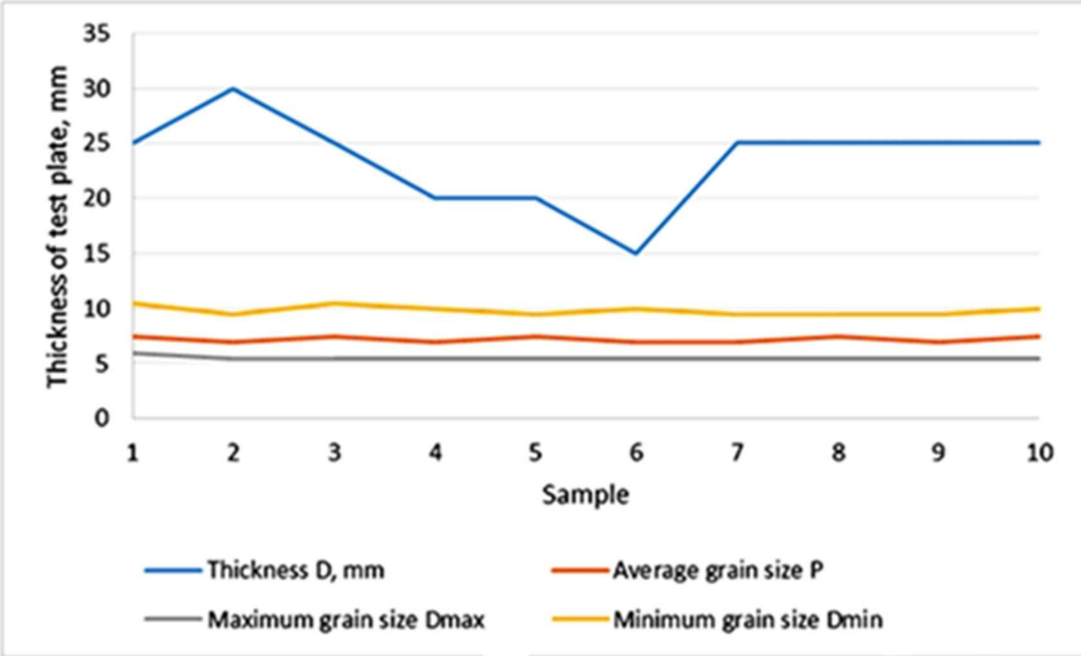


Figure 3. Grain size in accordance with plate thickness

Considering that standards EN 10025-6 [4,5] and DIN EN 10025-1 [3] for plates of these thicknesses, made of steel S690 QL, do not provide prescribed values for grain size and microstructure, the assessment was made based on comparing the results between individual plates. The analysis of the grain size for all samples showed that the results were uneven, ranging from a minimum size of 10.5 to a maximum size of 5.5. The Microstructure of samples after the heat treatment was generally fine-grained but an inhomogeneous structure with maximum or minimum grain size was noticed in the same places. It should be analysed in some future experiments. Some minor differences in grain size that exist between individual plate samples cannot be considered as a rule, which can be seen in the photomicrographs of characteristic samples 7 and 8 in Figure 2.

In general, it could be said that all the tested plates have a fine-grained tempered microstructure with an average grain size of 7 and 7.5. In all slab samples, minor inhomogeneities are visible due to the presence of individual or small groups of larger grains up to 5 in size, but no difference in grain size was observed in slabs of different thicknesses.

4. CONCLUSIONS

By analysing the chemical composition of steel S690QL for all 5 melts, it was confirmed that the chemical composition in accordance with standard EN 10025-6 and DIN EN 10025-1 both according to the conditions for the main elements, as well as for additional requirements regarding the regulation of the nitrogen content and the elements that translate it into a stable microconstituent. All produced melts are made with a high degree of purity in terms of sulphur and phosphorus content. The grain size was measured for all plates to determine the degree of homogeneity. All tested plates have a fine-grained structure with an average grain size of 7 to 7.5. The minimum measured grain size was 10.5 and the maximum size of 5.5. The minimum and maximum sizes refer to individuals or groups of grains. This means that there is inhomogeneity in microstructure i.e. the presence of an individual or smaller groups of larger (5.5) and finer grains (10.5). It can be assumed that such grains are associated with an uneven distribution of certain elements, i.e. insufficient concentration in micro surfaces (especially those that affect the grain size through the precipitation of their compounds). The heat treatment by quenching and tempering on the test samples indicates the presence of a fine-tempered microstructure.

5. REFERENCES

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