The effect of the heat treatment on the 7CrMoVTiB10-10 steel's microstructure and its properties

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According to the European Standard PN-EN 10216-2 two types of the heat treatment could apply to 7CrMoVTiB10-10 – the modern bainitic boiler steel. The 7CrMoVTiB10-10 steel may have different properties, depending on the chosen method of the heat treatment. This paper shows the differences in the microstructure and the properties occuring after two processes: one of them including normalization and tempering, and the other – hardening and tempering.

Key words: steel, microstructure, heat treatment, 7CrMoVTiB10-10, normalizing, hardening, tempering

Introduction

The heat treatment is used to alter the microstructure and, consequently, the properties of steel. Those mechanical properties depend on the type of the heat treatment. European Standard PN-EN 10216-2:2002 defines the conditions of technical delivery of seamless steel tubes for pressure purposes. Some details of the heat treatment of the 7CrMoVTiB10-10 seamless steel tubes are described in this standard. The above mentioned norm describes two types of the heat treatment which are acceptable for 7CrMoVTiB10-10. The basic kind of the heat treatment is the one involving normalizing and tempering. Hardening and tempering can be employed when the wall thickness is bigger than 16 mm, or if the ratio of the wall thickness to the tube diameter is more than 0.15. The aim of this paper is to show the differences between the microstructure and the properties of hardened and tempered samples and of those samples which were subjected to normalizing and tempering.

Material

The tested material was the 7CrMoVTiB10-10 steel. The chemical composition of 7CrMoVTiB10-10 is shown in Table 1.

Methodology

Heat treatment

Material were subjected to the heat treatment before research. The parameters of the heat treatment of 7CrMoVTiB10-10 steel are given in Table 2.

The exact parameters of the heat treatment of normalized and tempered specimens are not known because this type of the heat treatment was conducted by the producer of a pipe.

Microstructure examination

The ingredients of an etching reagent used for revealing the microstructure of 7CrMoVTiB10-10 were: 97 cm^3 of ethyl alcohol and 3 cm^3 of nitric acid. The microstructure was observed using an MA-200 microscope.

Tensile test

Six tensile specimens used for testing were cut from a tube. The drawing of a sample is shown in Figure 1. The real image of specimen is presented in Figure 2.

Three of the specimens were normalized and tempered, and the other three were hardened and tempered.

Table 1. The chemical composition of the 7CrMoVTiB10-10 steel

Steel	Chemical composition [%]							
	C	Mn	Si	Cr	Mo	V	Ti	B
7CrMoVTiB10-10	0.05	0.3 – 0.7	0.15 – 0.45	2.2 – 2.6	0.9 – 1.1	0.2 – 0.3	0.06 – 0.1	0.0015 – 0.007

Table 2. The parameters of the heat treatment of 7CrMoVTiB10-10

Type of heat treatment	Operation	Temperature [°C]	Time of heating [min]	Type of cooling
Normalizing and tempering	Normalizing	980-1020 (according to the PN-EN 10216-2:2002)	Unknown (estimated time – 30 min)	Air-cooling
	Tempering	730-770 (according to the PN-EN 10216-2:2002)	Unknown (estimated time – 30 min)	Air-cooling
Hardening and tempering	Hardening	980	30	Water-cooling
	Tempering	670	30	Air-cooling

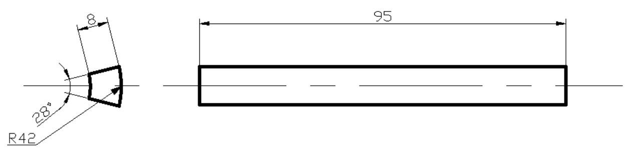

Figure 1.The drawing of a specimen for tensile test

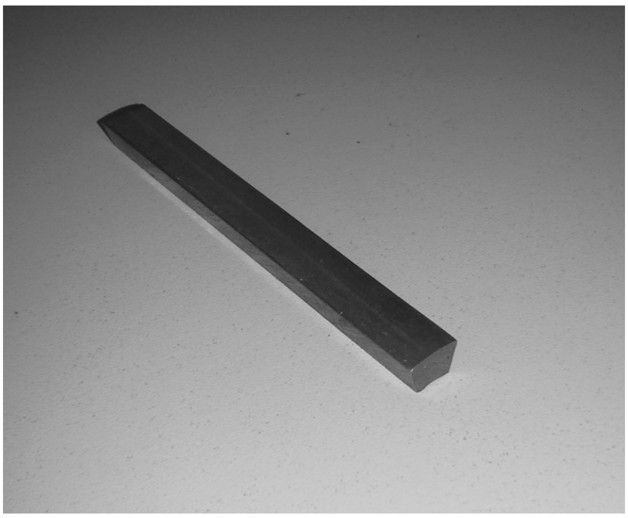

Figure 2. The real image of a specimen for tensile test

Hardness examination

Hardness was mczareasured in the normalized and tempered specimen and in the specimen after hardening and tempering. Five measurements in both specimens was carried out in Vickers scale (HV10). Hardness tester NEXUS 4000 produced by INNOVATEST was used to conduct the hardness examination.

Results

The microstructure of the 7CrMoVTiB10-10 steel after normalization and tempering is shown in Figures: 3 ÷ 6. The enlargements used during the observation of the microstructure presented in these pictures are different.

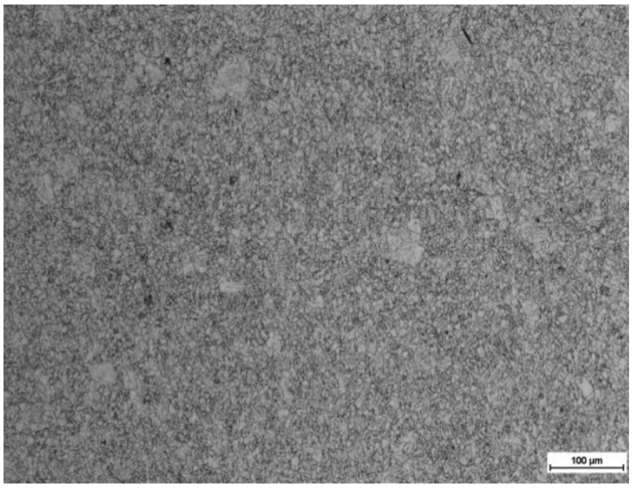

Figure 3. The microstructure of 7CrMoVTiB10-10 after normalizing and tempering

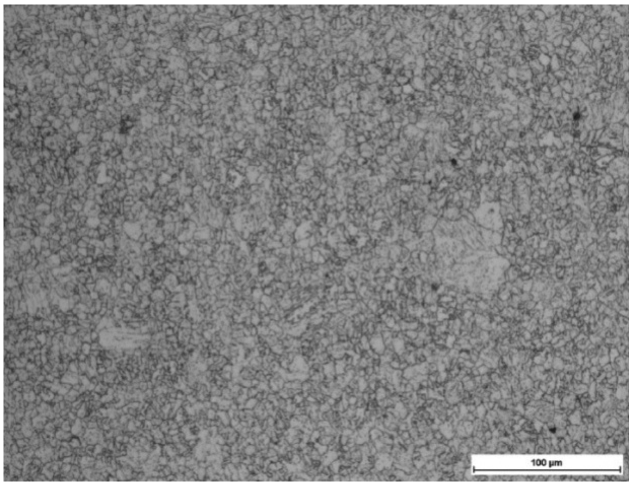

Figure 4. The microstructure of 7CrMoVTiB10-10 after normalizing and tempering

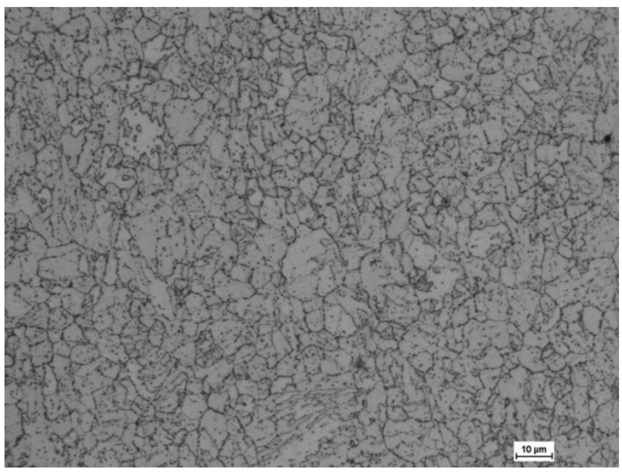

Figure 5. The microstructure of 7CrMoVTiB10-10 after normalizing and tempering

The microstructure of the material subjected to hardening and tempering is presented in Figures: 7 ÷ 10. During observations of the microstructure shown in each of the pictures different enlargement were used.

The specimens after the completion of the tensile test are shown in Figure 11. The hardened and tempered spec-

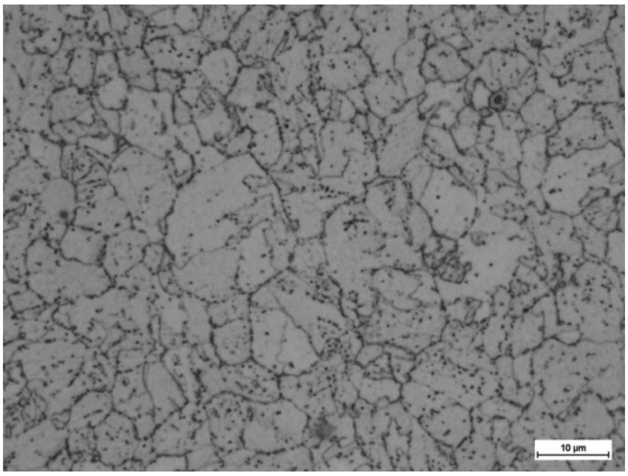

Figure 6. The microstructure of 7CrMoVTiB10-10 after normalizing and tempering

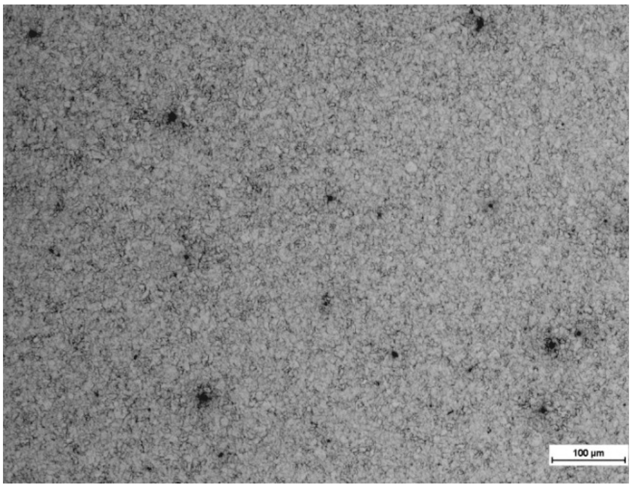

Figure 7. The microstructure of 7CrMoVTiB10-10 after hardening and tempering

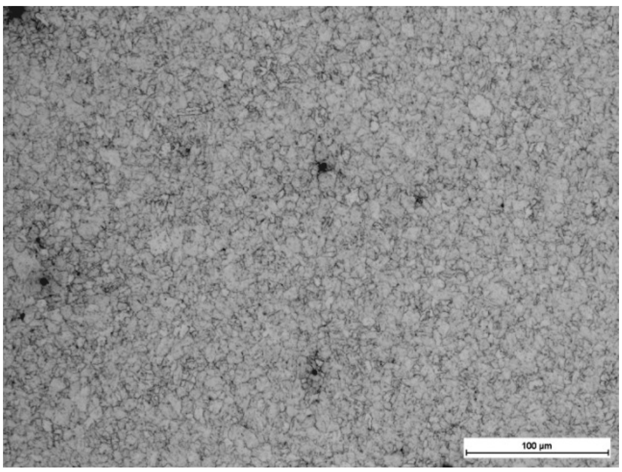

Figure 8: The microstructure of 7CrMoVTiB10-10 after hardening and tempering

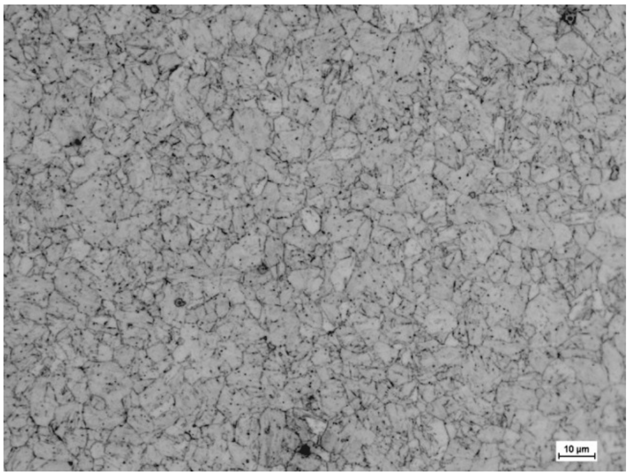

Figure 9. The microstructure of 7CrMoVTiB10-10 after hardening and tempering

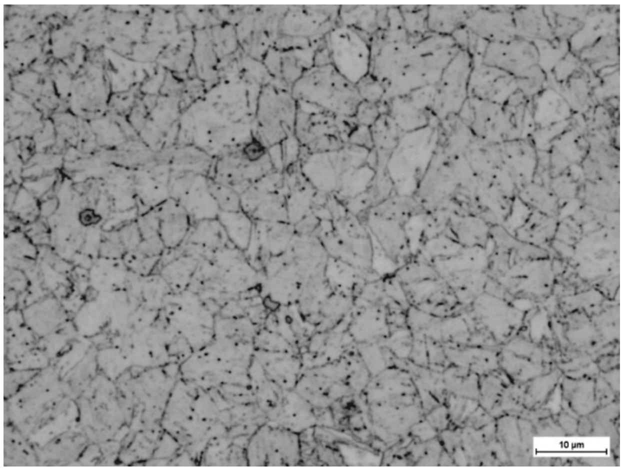

Figure 10. The microstructure of 7CrMoVTiB10-10 after hardening and tempering

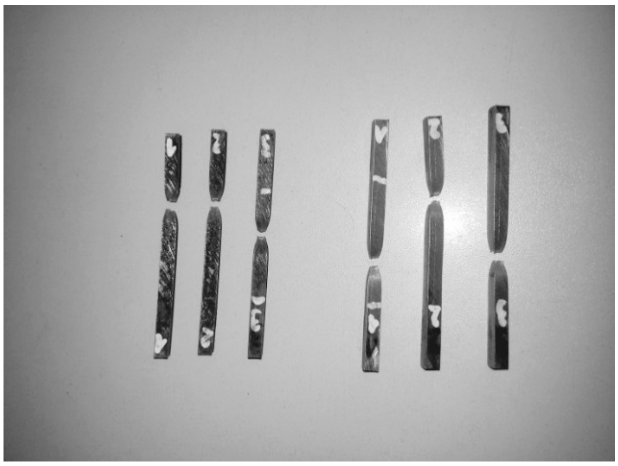

Figure 11. The specimens after completion the tensile test

imens are placed on the left side and specimens subjected to normalizing and tempering - on the right side.

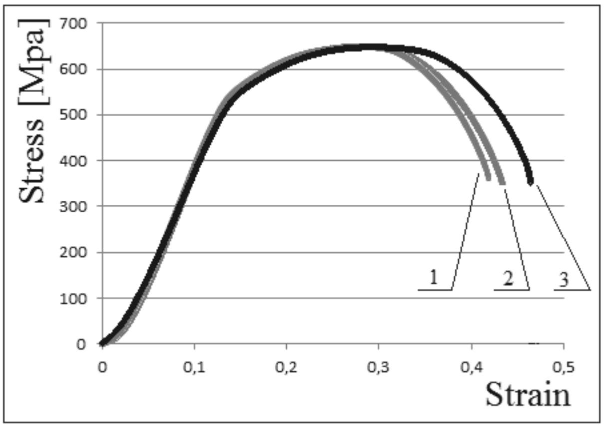

Figure 12. The tensile test diagrams for the normalized and tempered specimens: 1 – the first sample, 2 – the second sample, 3 – the third sample

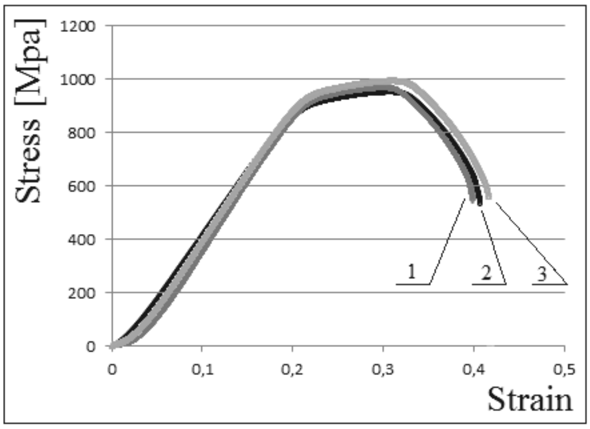

Figure 13. The tensile test diagrams for the hardened and tempered specimens: 1 – the first sample, 2 – the second sample, 3 – the third sample

Table 3. The values of yield strength and tensile strength for the tested specimens after normalizing and tempering

Properties	The number of the specimen		
	1	2	3
The value of yield strength [MPa]	550	550	550
The value of tensile strength [MPa]	648	650	649

Table 4. The values of yield strength and tensile strength for tested specimens after hardening and tempering

Properties	The number of the specimen		
	1	2	3
The value of yield strength [MPa]	910	930	950
The value of tensile strength [MPa]	954	970	994

Table 5. The values of hardness for tested specimens after normalizing and tempering

Property	The number of a measurement					Average value
	1	2	3	4	5	
Hardness (HV10)	212	213	214	212	215	213

Table 6. The values of hardness for tested specimens after hardening and tempering

Property	The number of a measurement					Average value
	1	2	3	4	5	
Hardness (HV10)	355	357	362	358	355	357

The diagrams resulted from the tensile tests conducted for all the specimens are shown in Figure 12 and Figure 13.

The values of yield strength and tensile strength for tested specimens after normalizing and tempering are presented in Table 3.

The values of yield strength and tensile strength of the hardened and tempered specimens are detailed in Table 4.

Table 5 shows the values of hardness of the normalized and tempered specimens.

The values of hardness of the specimens subjected to hardening and tempering are presented in Table 6.

Discussion

The observations of the microstructure of the 7CrMoVTi B10-10 steel show the grain size after normalizing and tempering differs from that obtained after hardening and tempering. The average grain size of the 7CrMoVTiB10-10 steel after normalizing and tempering is 10 µm. The grain size of the material subjected to hardening and tempering is approximately 5µm. The mechanical properties of materials are conditioned by, among other things, the size of grains. The yield strength, the tensile strength and the elongation are different for the material subjected to normalizing and tempering and for the hardened and tempered material. The values of yield strength and tensile strength for the steel subjected to hardening and tempering are approximately 350 MPa higher than the values of yield strength and tensile strength for the normalized and tempered material. The value of strain is higher for 7CrMo VTiB10-10 after normalization and tempering - it equals approximately 0,43. The value of strain of the hardened and tempered material equals approximately 0,41. The average hardness of the normalised and tempered specimen equals 213 HV10. For the specimen hardened and tempered the average hardness equals 357 HV10. Heat treatment which includes hardening and tempering is called toughening. The grain size is not the only factor responsible for the differences recounted above. Other reasons are as follows: the bainitic microstructure is created after hardening and the perlitic microstructure after normalization in case of 7CrMoVTiB10-10. Bainite has higher values of yield strength, tensile strength and hardness than perlite even after tempering whereas perlite has higher values of elongation and reduction of the area at fracture. Additionally, some austenite transform to martensite during bainite reaction. This transformation also increases the values of yield strength, tensile strength and hardness of the hardened and tempered specimens.

Conclusions

The conditions of the technical delivery (including heat treatment) of the material are the one of key factors in processes of manufacturing the crucial elements responsible for the reliability and safety of machines (boiler in power plant – in case of 7CrMoVTiB10-10). The same material may have different properties according to the chosen type of the heat treatment. The values of the tensile strength, the yield strength and the hardness were higher for the fine-grained, bainitic microstructure which was obtained by hardening and tempering. 7CrMoVTiB10-10 is used for pressurized elements so its mechanical properties are very important. The type of the heat treatment is very important and it should be taken into account while placing an order for parts made of the 7CrMoVTiB10-10 steel. The hardened and tempered steel is often more expensive than the normalized and tempered material, but it should be chosen if it is intended to work under the load which is too high for the 7CrMoVTiB10-10 steel subjected to normalizing and tempering.

References

[1] Przybyłowicz K.: Metaloznawstwo, Wydawnictwa Naukowo – Techniczne, Warszawa 2007.

[2] PN-EN 10216-2:2002 – Rury stalowe bez szwu do zastosowań ciśnieniowych – Warunki techniczne dostawy – Część 2: Rury ze stali niestopowych i stopowych z określonymi własnościami w temperaturze podwyższonej.

[3] Dobrzański L.: Materiały inżynierskie, Wydawnictwa Naukowo – Techniczne, Warszawa 2007.

[4] Dobrzański L.: Metaloznawstwo i obróbka cieplna, Wydawnictwa Naukowo – Techniczne, Warszawa 1997.

[5] Taler J.: Procesy cieplna i przepływowe w dużych kotłach energetycznych, Wydawnictwo Naukowe PWN, Warszawa 2011.

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Paweł Bolanowski obtained his Master of Science degree in Mechanical Engineering from the Kielce University of Technology in 2010. He worked in the following positions: Welding Technologist at CHEMAR Armatura (2010-2012) and Welding Engineer at Energomontaż Południe (contract job in Mannheim – Germany) (2012). He joined the Department of Applied Computer Science and Armament Engineering of Kielce University of Technology as a PhD Student in 2012.