EFFECT OF MIXING OF COOLING MEDIA ON MICROSTRUCTURE AND HARDNESS OF STEEL 23MnB4

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ABSTRACT
Steel cooling is an important technological operation because the final microstructure of the steel, and therefore its properties, depends on the cooling rate. The speed of steel cooling depends on numerous factors, one of which is the movement of the cooling media. This paper presents the results of testing the influence of mixing the cooling media on the microstructure and hardness of 23MnB4 steel. Two media that are usually used for quenching steel (water and oil) were used for the test. The samples were cooled in an unstirred media and in a stirred media with three different stirring speeds (500, 750, and 1000 rpm). The results showed that mixing the media has an influence on the microstructure and hardness of steel. Samples that were cooled in a mixed medium had a higher hardness. The mixing speed had a greater influence on the hardness in the case of cooling in water. The microstructure after cooling in the water and oil was martensite-bainite. With an increasing cooling rate, the ratio of martensite in microstructure increases.

1. INTRODUCTION

Steel cooling is an extremely important technological operation during the heat treatment of steel because the final microstructure of the steel, and therefore its properties, depends on the cooling rate. In practice, three methods of cooling are usually distinguished; slow, normal, and fast. Slow cooling is the cooling of samples in the furnace and is most often used in the annealing process. Normal cooling is carried out in the air, as in the case of normalization. Rapid cooling is applied during quenching and has the greatest impact on microstructure and properties. The cooling rate is affected by various factors such as:

- type of media used (initial temperature, boiling point, specific heat, thermal conductivity, viscosity, etc.),
- media movement,
- type of material being cooled (chemical composition, thermal conductivity, and specific heat),
- the mass of the samples, the ratio of surface area and volume,
- condition of the surface of the sample being treated, and
- sample design.

Of the mentioned factors that affect the cooling rate, in practice, only the medium used for cooling can be influenced, that is, the correct choice of the cooling media and its mixing [1-3].

The aim of the test is to show whether the mixing of media during quenching affects the microstructure and hardness of 23MnB4 steel.

2. EXPERIMENTAL PART

The material tested in this work was the steel 23MnB4 with a chemical composition given in Table 1. Because the tested samples are taken from the screw, the chemical composition is given according to the standard EN 10263-4: 2001 Steel rod, bars, and wire for cold heading and cold extrusion, Technical delivery conditions for steels for quenching and tempering.

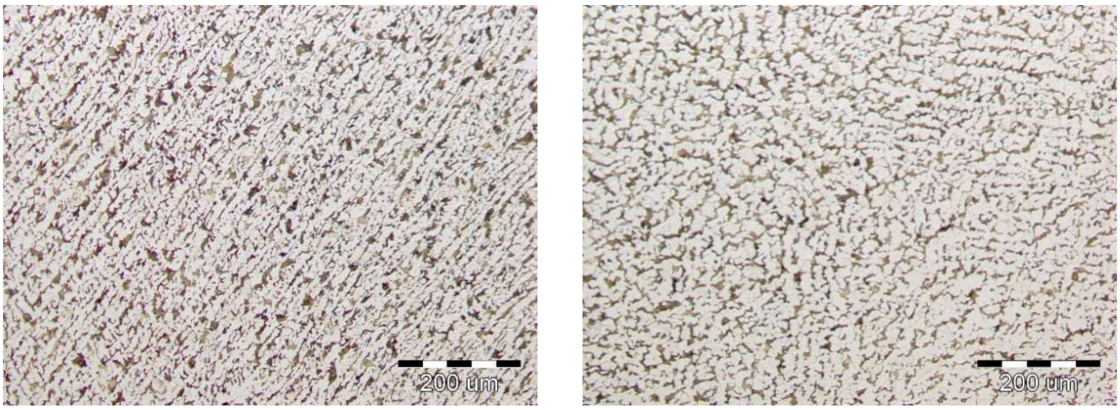
Table 1. Chemical composition of 23MnB4 [4]

Chemical composition [wt.%]	C	Si_{max}	Mn	P_{max}	S_{max}	Cr_{max}	Cu_{max}	B
	0.20-0.25	0.30	0.90-1.20	0.025	0.025	0.30	0.25	0.0008-0.005

The analysis of a microstructure and hardness were done for the initial state and 8 quenched samples cooling with different rates (no mixing, 500, 750, and 1000 rpm) in two cooling media (water and oil). The samples were cylindrical in shape dimension Ø18x10 mm. The heating temperature was 880 ºC and the samples were heated together with a furnace at room temperature. The quantity of cooling media was a two-liter. Digital overhead Stirrer LLG-uni STIRRER OH2 used for stirring, Figure 1. The speed range of the stirrer is from 50 to 2200 rpm.

Figure 1. Digital overhead Stirrer LLG-uni STIRRER OH2

Before analysis of microstructure, the samples were prepared by grinding, polishing, and etching by nital (HNO_3 + ethanol). The microstructural analysis was carried out by the Olympus optical microscope with a maximum magnification of x1000. The microstructure of the initial state is shown in Figure 2. The microstructure is the ferrite-pearlite. From the figures, it could be noticed that the microstructure on the surface is more directed than in the center.



a) b)

Figure 2. The microstructure of the initial state: a) surface and b) center, x100

Hardness tests, according to standard BAS EN ISO 6506-1:2015 and BAS EN ISO 6508-1:2017were performed on specimens prepared for microstructure analysis.

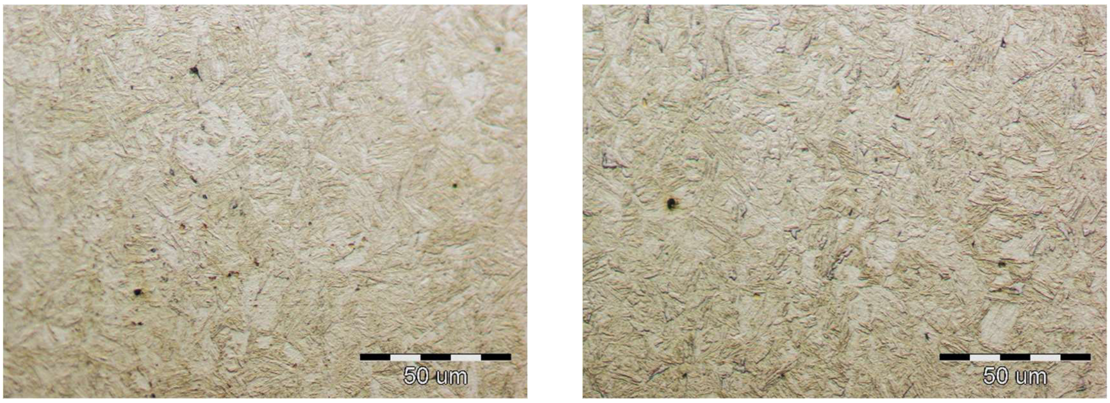
3. RESULTS AND DISCUSSION

3.1. Analysis of microstructure

The microstructure of the quenched samples in the different media with different cooling rates is shown in Figures 3 to 10. All samples showed fine-grained microstructure.

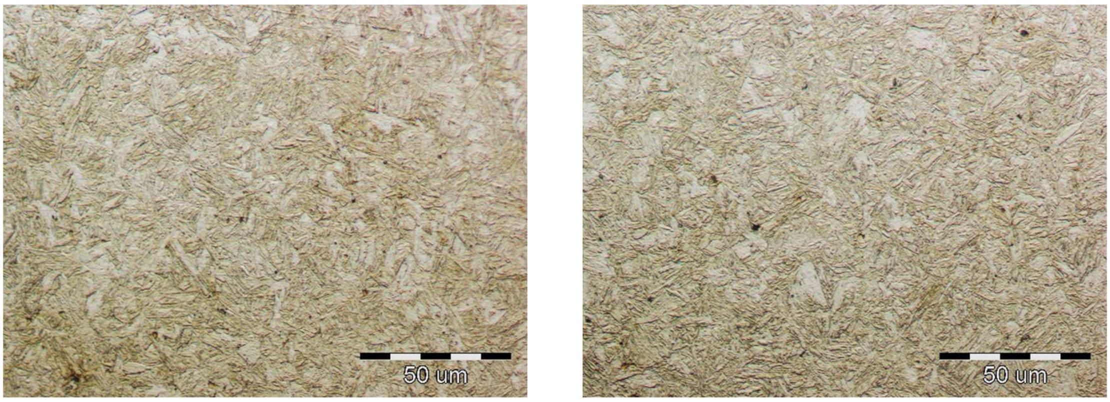
a) b)

Figure 3. The microstructure of the sample cooled in the water without mixing: a) surface and b) center, x500



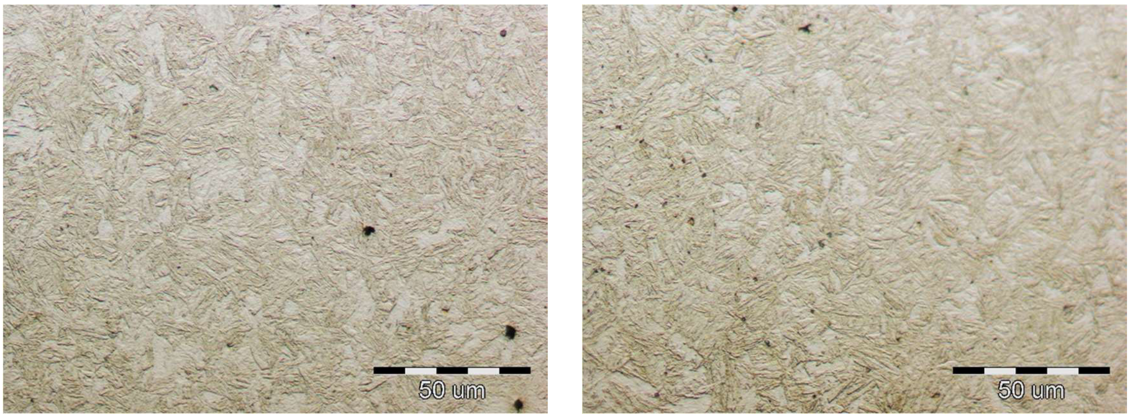
a) b)

Figure 4. The microstructure of the sample cooled in the water with mixing of 500 rpm: a) surface and b) center, x500



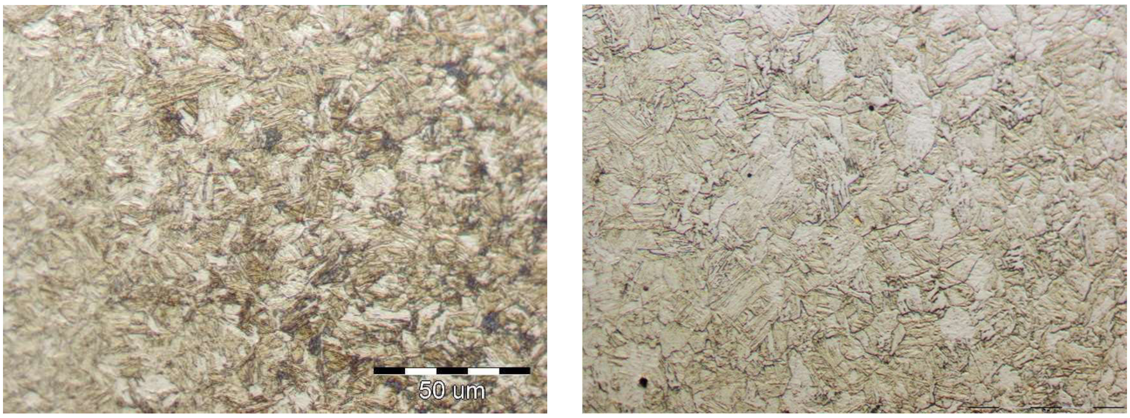
a) b)

Figure 5. The microstructure of the sample cooled in the water with a mixing of 750 rpm: a) surface and b) center, x500



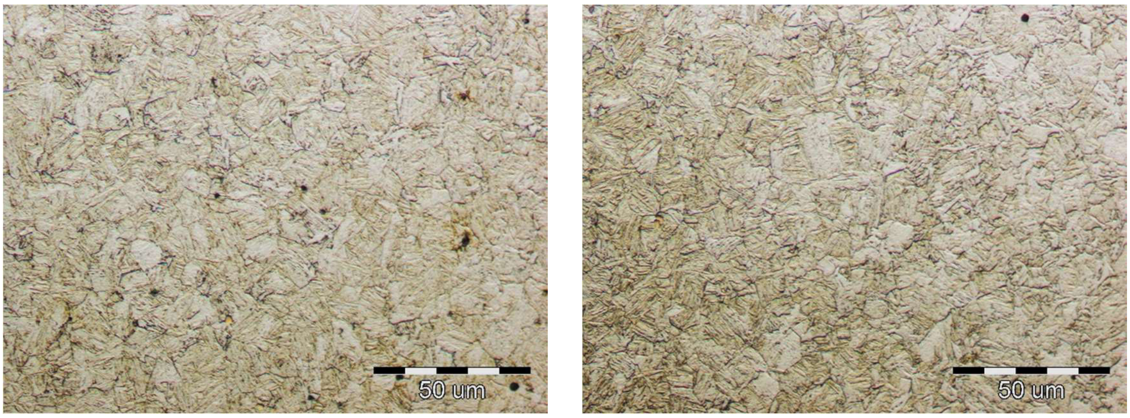
a) *b)*

Figure 6. The microstructure of the sample cooled in the water with a mixing of 1000 rpm: a) surface and b) center, x500



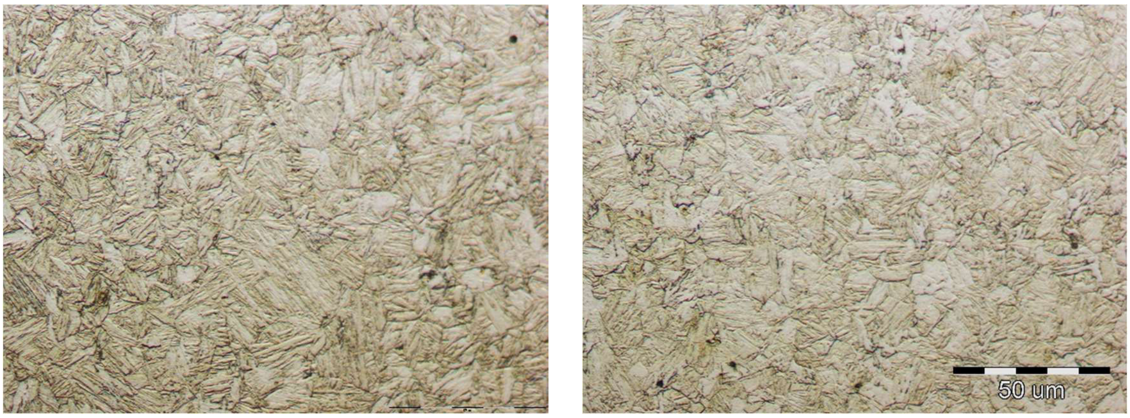
a) *b)*

Figure 7. The microstructure of the sample cooled in the oil without mixing: a) surface and b) center, x500



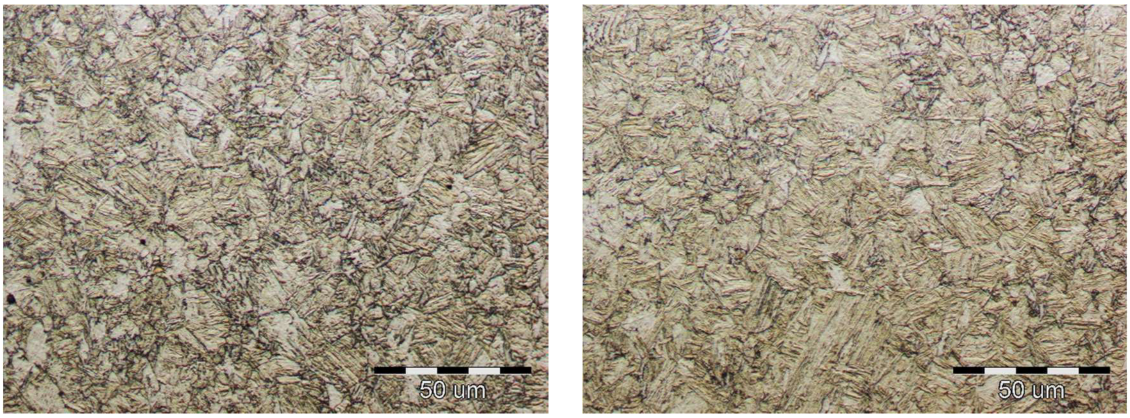
a) *b)*

Figure 8. The microstructure of the sample cooled in the oil with a mixing of 500 rpm: a) surface and b) center, x500



a) b)

Figure 9. The microstructure of the sample cooled in the oil with a mixing of 750 rpm: a) surface and b) center, x500



a) b)

Figure 10. The microstructure of the sample cooled in the oil with a mixing of 1000 rpm: a) surface and b) center, x500

Analysis of the microstructure after cooling in the water and oil showed the martensite-bainite microstructure. After quenching in oil the microstructure was more bainite (Figure 7-10) while the microstructure after cooling in water was martensite with bainite (Figure 3-6) because the cooling rate was faster. The microstructure is the same on the surface and center of the sample. For these dimensions, the steel has good hardenability.

3.2 Analysis of hardness

The results of the hardness analysis are presented in Table 2.

Table 2. Analysis of hardness

Sample	Cooling mode	Hardness (HBW 2,5/187,5)						Hardness [HV]*
		Single values					Average	
Sample 1 (initial state)	-	184	187	187	184	187	**186**	**184**
		Hardness (HRC)						
		Single values					Average	
Sample 2 (quenching in water)	No mixing	41	42	42	42	43	**42**	**406**

Sample	Cooling mode	Hardness (HBW 2,5/187,5)						Hardness [HV]*
		Single values					Average	
Sample 1 (initial state)	-	184	187	187	184	187	**186**	**184**
		Hardness (HRC)						
		Single values					Average	
Sample 3 (quenching in water)	500 rpm	44	46	42	46	44	**44**	**438**
Sample 4 (quenching in water)	750 rpm	47	47	46	47	48	**47**	**474**
Sample 5 (quenching in water)	1000 rpm	49	49	49	47	48	**48**	**490**
Sample 6 (quenching in oil)	No mixing	38	38	38	39	39	**38**	**361**
Sample 7 (quenching in oil)	500 rpm	41	42	42	41	41	**41**	**393**
Sample 9 (quenching in oil)	1000 rpm	41	41	42	42	43	**42**	**406**
Sample 8 (quenching in oil)	750 rpm	41	41	42	42	42	**42**	**406**

*https://www.steelexpress.co.uk/steel-hardness-conversion.html

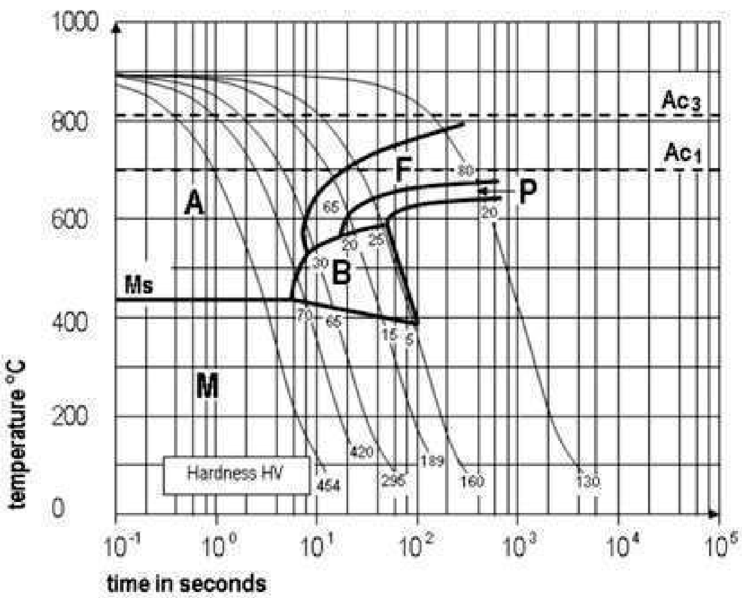


Figure 11. CCT diagram for steel 23MnB4 [4]

The hardness analysis showed that the samples cooled in water have a higher hardness compared to the samples cooled in oil. The rate of oil mixing did not significantly affect the cooling rate of the samples, except in the case that the oil mixing resulted in a hardness that could be achieved by cooling in water without mixing. The rate of water mixing

affected the rate of cooling. As the mixing speed increases, the hardness of the samples increases.
According to the literature [4] from the analysis of the CCT diagram (Figure 11) it can be seen that the hardness values obtained for cooling in oil correspond to the area of transformation of austenite into martensite and bainite. The hardness obtained for higher cooling rates, i.e. water mixing, corresponds to the transformation of austenite into martensite. With an increase in the cooling rate, the proportion of martensite in the martensite-bainite microstructure also increases. For mixing speeds of 500, 750, and 1000 revolutions, 100% martensite is obtained.

4. CONCLUSIONS

The aim of the test is to show whether the mixing of media during quenching affects the microstructure and hardness of 23MnB4 steel. The initial microstructure of steel was ferrite-pearlite. Analysis of the microstructure after cooling in the water and oil showed the martensite-bainite microstructure. Samples that were cooled in a mixed medium had a higher hardness. The mixing speed had a greater influence on the hardness in the case of cooling in water. With an increasing cooling rate, the ratio of martensite in microstructure increases. The rate of oil mixing did not significantly affect the cooling rate of the samples, except in the case that the oil mixing resulted in a hardness that could be achieved by cooling in water without mixing. After quenching, the microstructure is the same on the surface and center of the sample. For these dimensions, the steel has good hardenability.
In the end from the results, it could be concluded that the mixing process has an influence on the cooling rate of the steel 23MnB4. With mixing, it is possible to get the same hardness for steel quenched in the oil as the cooling in water without mixing. The mixing rate has more influence on the cooling in water than in the oil.

5. ACKNOWLEDGMENT

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