MANDREL BARS RECOVERY OF PROPERTIES BY QUENCHING AND TEMPERING PROCESS*

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Abstract
Mandrels are tools applied to manufacturing seamless tubes. In VSB plants (Vallourec Soluções Tubulares do Brasil), it is used in two mills. Mandrel and PQF Mills. This is an expensive tool due its alloy (hot work tool steel – AISI H13) and lengh (between 12 meters and 22,5 meters). An opportunity to apply mandrels from PQF in Mandrel Mill has been identified. However, mechanical properties of PQF mandrels must be improved. This work presents the heat treatment process of Quenching and Tempering developed internally at VSB to improve PQF mandrel properties aiming to achieve Mandrel Mill requirements. Hardness and metallography tests were performed before and after some steps of the heat treatment to characterize and validate the process.
Keywords: Quenching; third tempering; mandrel; hardness

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1 INTRODUCTION

Mandrels are tools used in forming process of manufacturing seamless tubes. In VSB plants, they are applied in PQF and Mandrel Mills. It is made of AISI H13 steel due its properties of great toughness and fatigue resistance at high temperature. Mandrel bars are expensive tools due its alloy and length, which varies from 12 meters to 22,5 meters. Aiming to reduce costs, an opportunity to apply PQF mandrel bars in Mandrel Mill was identified. However, mechanical properties must be improved. The quenching and tempering heat treatment operations are widely applied in ferrous alloys and aims to produce a structure that allows the material acquire properties of hardness and mechanical strength compatible with the conditions of their use [1]. So, it was developed internally in VSB a heat treatment process (quenching and tempering) aiming to make PQF mandrel bars meet Mandrel Mill requirements. Mechanical and metallurgical characterization were performed.

2 MATERIAL AND METHODS

2.1 Samples

The PQF mandrel bars dimensions are OD 182mm x 12.500mm. They are made of AISI H13 steel.

Table 1: AISI H13 steel chemical composition

C	Mn	Si	Cr	Mo	V
0.40	0.40	1.00	5.25	1.35	1.00

2.2 Heat treatment

The heat treatment dimensioning were based on the AISI H13 Continuous Cooling Transformation Diagram (Figure 1), Tempering Diagram (Figure 2) and Tempering Temperature x Mechanical Properties Diagram (Figure 3) [2].

It is expected to quenching and tempering the mandrel bars to increase its hardness from 34HRC (material already Q&T by supplier) to 45 HRC +/- 2 HRC.

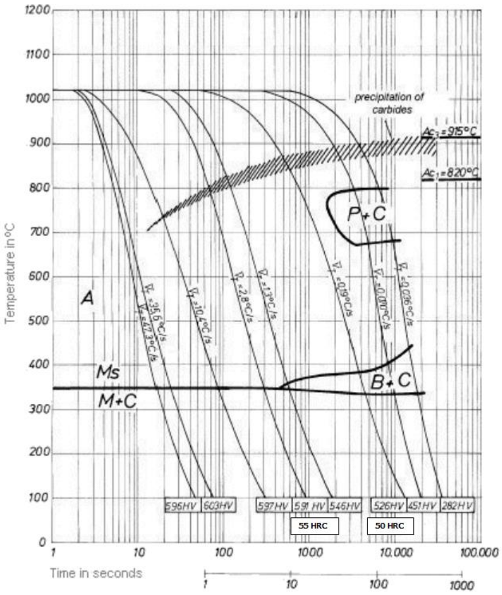


Figure 1: Continuous Cooling Transformation Diagram.

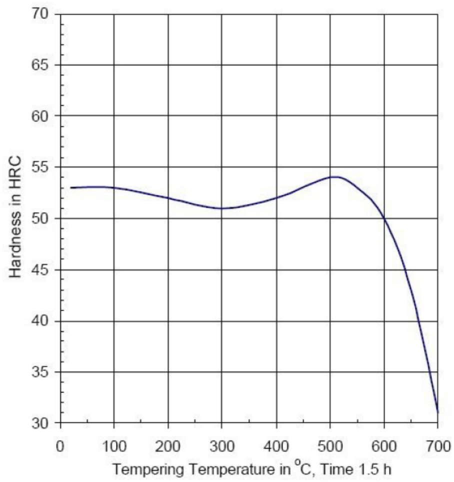


Figure 2: Tempering Diagram.

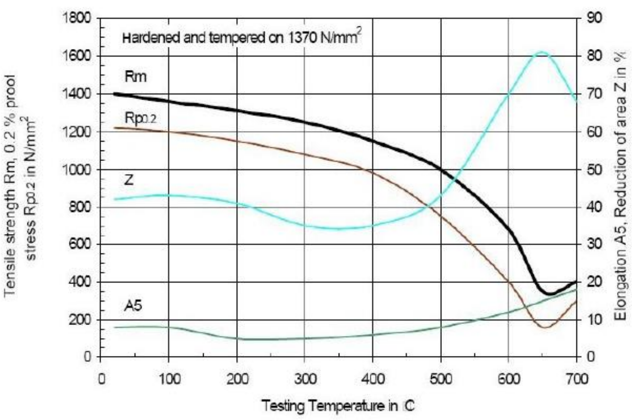
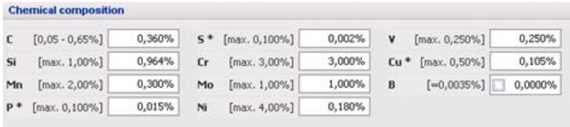


Figure 3: Diagram Tempering Temperature x Mechanical Properties.

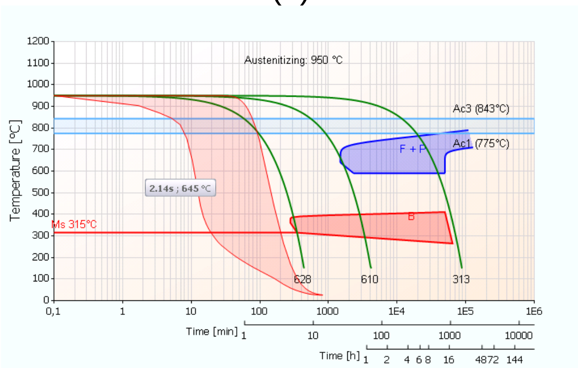
Besides the diagram informations and analysis, a ThermoCalc simulation was carried out to a more precisely dimensioning of the heat treatment.



Chemical composition

C	[0,05 - 0,65%]	0,360%	S *	[max. 0,100%]	0,002%	V	[max. 0,250%]	0,250%
Si	[max. 1,00%]	0,964%	Cr	[max. 3,00%]	3,000%	Cu *	[max. 0,50%]	0,105%
Mn	[max. 2,00%]	0,300%	Mo	[max. 1,00%]	1,000%	B	[=0,0035%]	0,0000%
P *	[max. 0,100%]	0,015%	Ni	[max. 4,00%]	0,180%			

(a)



(b)

Figure 4: (a) Chemical Composition Simulated in ThermoCalc. (b) ThermoCalc simulation result.

As the figure 4(a) shows, the mandrel bar chemical composition simulated is different in comparison with AISI H13, due to the software restraints. However, it was tested at the closest chemical composition possible. This information was useful for guidance.

It is expected that tempering leads to the precipitation of carbide particles and significantly decreases the carbon content in the solid solution and the dislocation density [3].

So, after the studies performed, the heat treatment process was proposed (Table 2).

Quenching in water was chosen to ensure higher hardness throughout the mandrel bars dimensions.

The triple tempering were specified to improve toughness and reduce hardness variability.

2.3 Characterization

2.3.1 Hardness

The hardness evaluation consists in cutting a mandrel bar in its cross section and three conditions: in the original condition, after quenching and after the third tempering cycle.

The hardness test applied was Rockwell C, with 15kgf of load and diamond indenter. It is in compliance with ASTM E 18 [4].

In each condition, the sample were evaluated with seven indentations distributed from the material surface to the core (A to G). The hardness test indentations were distribuited as indicated in the following figure (figure 5).

Table 2: Quenching and tempering parameters

Process	Temperature (°C)						Cycle (s)	Soacking time (min)	Quenching rings			Descaling (number of spray)	Deflectors (for 193,7mm)	Process time
	Tempering furnace				Soaking furnace									
	Mandrel (before pre heating)	Pre heating	Heating	Floor	Soaking	Mandrel (soaking)			Flow (m³/h)	Speed (m/min)	Number of rings			
Quenching	-	650	990	850	1010	970	288	46	280	3	6	12	Yes	4h
1° Tempering	< 100	483	488	453	488	-	448	215	-	-	-	12	-	9h40min
2° Tempering	< 100	595	600	565	600	-	435	215	-	-	-	12	-	9h31min
3° Tempering	< 100	545	550	515	550	-	440	214	-	-	-	12	-	9h31min

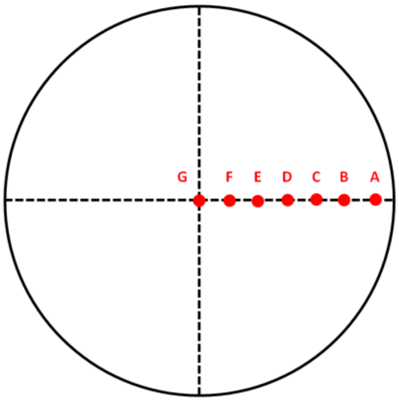


Figure 5: Indentation regions – hardness test.

2.3.2 Metallography

Mandrel bars structure evaluation were carried out in three conditions: in the original condition, after quenching and after the third tempering cycle.

2.3.2.1 Macrography

The test comprises in:

1. Cut a mandrel section tranversely (sample);
2. Machine the samples to make the bottom and the top surfaces parallel.
3. Finishing the surface with griding process.
4. Etch the sample with HCl.

It is in compliance with ASTM A 561[5].

2.3.2.2 Micrography

It is expected to know what are the phases transformations over the mandrel radius in the three conditions evaluated. Micrography tests have been performed from the surface to the core.

The test comprises in:

1. Cut a mandrel section tranversely (sample);
2. Define regions of analysis;
3. Cut the sample into small parts (specimen dimensions);
4. Griding an polishing the specimens;
5. Etching the specimens;
6. Analyse the microstructure at microscope.

Micrography tests were performed in compliance with the standard ASTM E 407[6].

3 RESULTS AND DISCUSSION

The results are divided in three parts: process, mechanical and metallurgical.

3.1 Process results

The process has been controlled using not only the process control but also manual pyromether. The results measured were:

- Austenitizing Temperature: 1014 °C.
- Temperature after Quenching: 380 to 430 °C.

A critical aspect evaluated was concerning the presence of cracks in the mandrel surface. Dye penetrant test was performed. Cracks were observed neither before nor after the quenching and tempering process.

3.2 Mechanical results - hardness

Below the mandrel samples hardness values measured from the surface and down to the core is shown in figure 6:

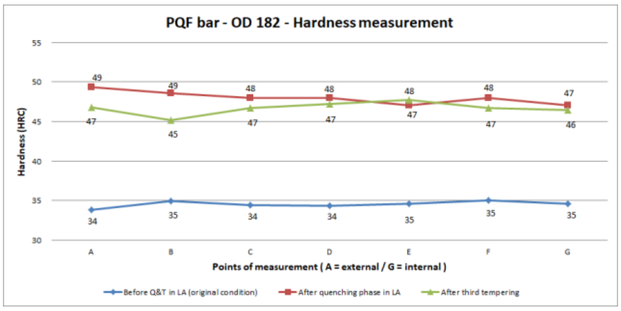


Figure 6: hardness values in the samples before quenching (♦), after quenching (■) and after third tempering cycle(▲).

3.3 Metallurgical results

The macrography and micrography test were carried out. The mandrel bar structure were evaluated in three conditions: original condition, after quenching and after third tempering cycle.

3.3.1 Macrography results

The following images shows the results related to each specimen.

Figure 7: Macrography at receipt condition.

Figure 8: Macrography after quenching.

Figure 9: Macrography after third tempering.

3.3.2 Micrography results

Micrography tests were carried out with magnification of 500x.

Specimens have been separated in four parts:

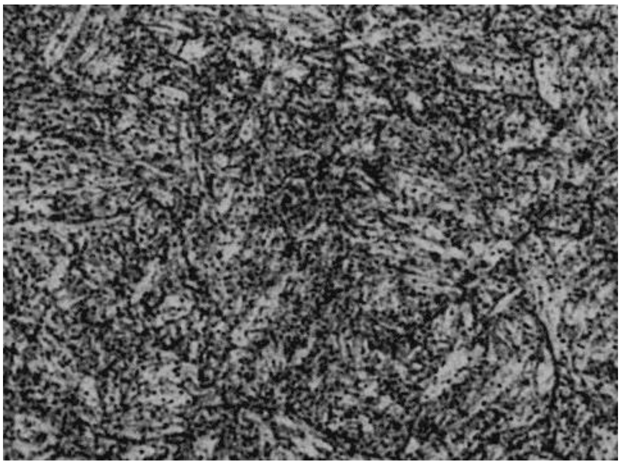
I → core
M1 e M2 → middle
E → external surface

Figure 10: Specimen identifications.

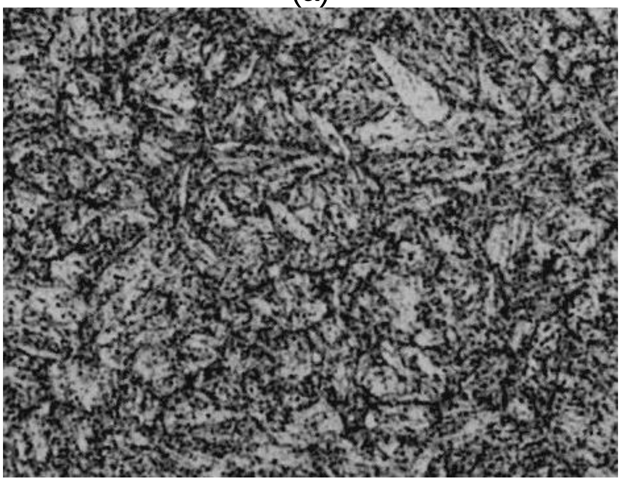
Microstructure analysis evaluates the samples structure from the surface to the core. It was performed in three conditions:

as received, after quenching and after third tempering cycle.

3.3.2.1 Microstructure before quenching – 500x magnification (as received)



(a)



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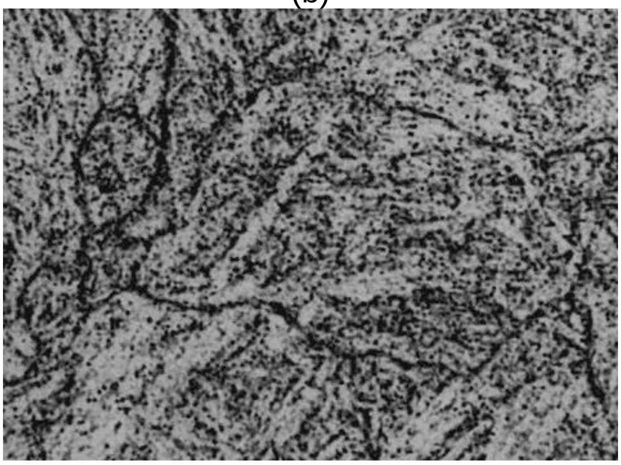
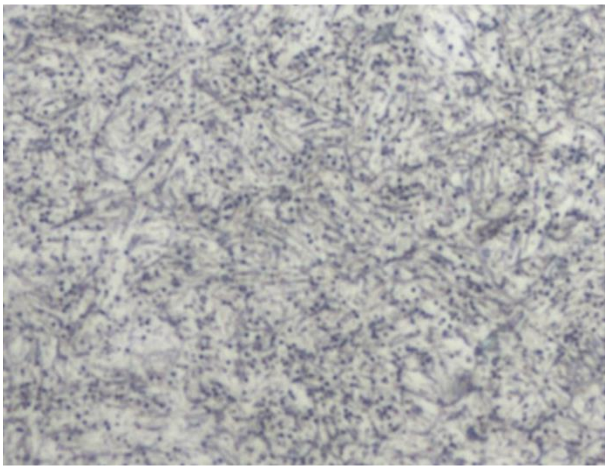


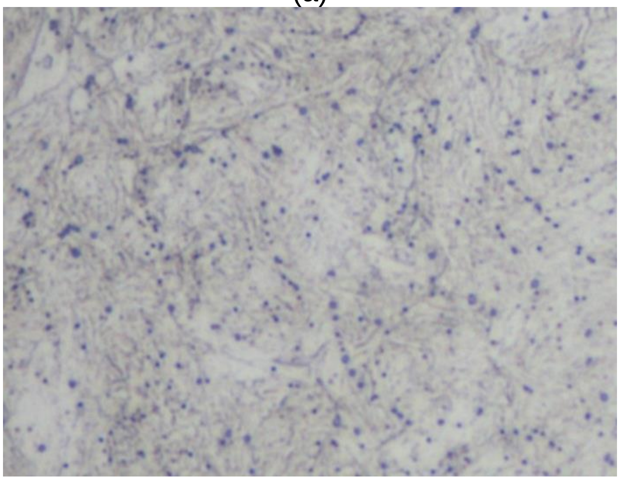
(c)

Figure 11: Mandrel bar structure as received – 500 x magnification – (a) region E; (b) M1 and M2; (c) I.

3.3.2.2 Microstructure after quenching – 500x magnification



(a)



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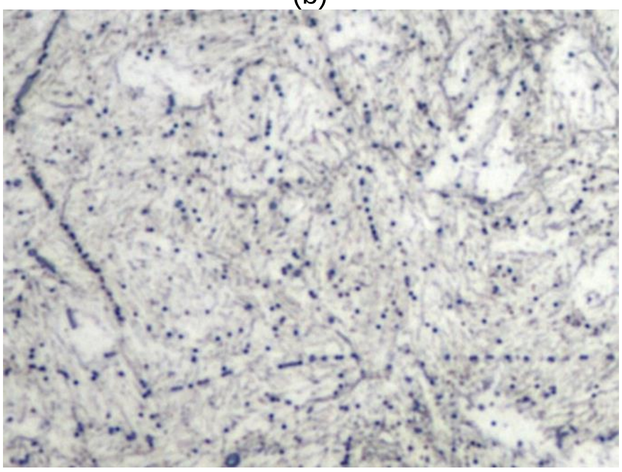

(c)

Figure 12: mandrel bar structure after quenching – 500 x magnification – (a) region E; (b) M1 and M2; (c) I.

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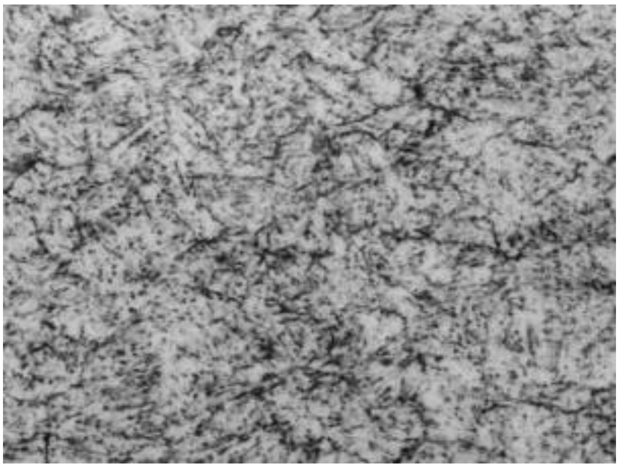
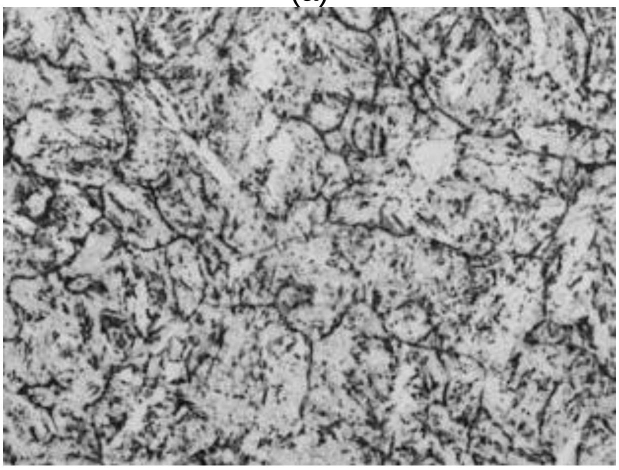
3.3.2.3 Microstructure after third tempering cycle – 500x magnification



(a)



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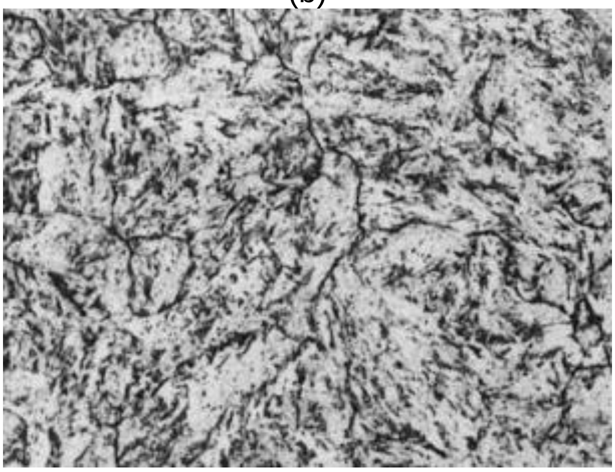
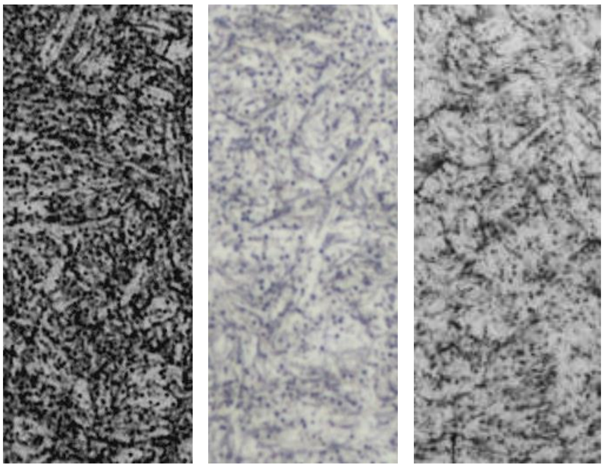


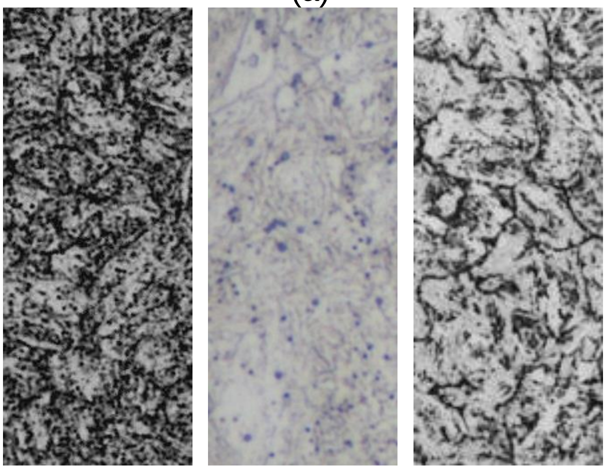
(c)

Figure 13: Mandrel bar structure after Q&T – 500 x magnification – (a) region E; (b) M1 and M2; (c) I.

3.3.2.4 Comparison among the structures in the three conditions and in the three specimens locations (E, M2, I).



(a)



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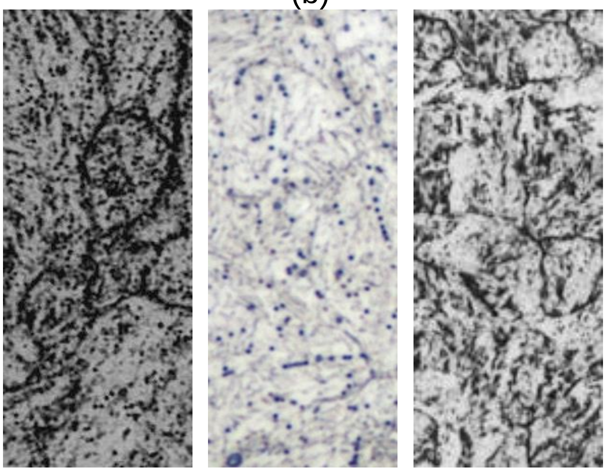

(c)

Figure 14: Comparison between structures of specimens in three conditions before quenching (as received), after quenching and after Third tempering cycle. (a)

specimens region E; (b) specimens region M1 and M2; (c) specimens I.

3.4 Discussion

Based on hardenability software, H13 CCT diagram, temperature measured after the quenching phase and hardness measured in the quenching and the Q&T specimens, the microstructure expected is: Bainite in the core (specimens M1, M2 and I) and tempered martensite (specimen E).

The microstructure of quenching phase does not reveal clearly the bainite or martensite formation due to the self-tempering. However, the difference of phase revealed by macrography suggests that external layer with 20 mm is formed by tempered martensite and the core is formed by bainite (see figure 8).

4. CONCLUSION

Quenching and Tempering line in VSB is able to increase the hardness of bars homogeneously in the cross section with low variability (2 HRC).

Macrography after quenching phase suggests a layer with 20 mm composed by refined martensite and the core composed by lower bainite + carbides.

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REFERENCES

1 Vicente CHIAVERINI – Tratamentos Térmicos das Ligas Metálicas. 1a . ed. São Paulo-SP, Editora Associação Brasileira de Metalurgia e Materiais, 2003.

2 SIJ GROUP. Sitherm 2344 steel. Disponível em: <https://steelselector.sij.si/steels/utopmo2.html>. Acesso em: 31 mai. 2019.

3 Vojteh LESKOVSEK , Borivoj SUSTARSIC, Gorazd JUTRISA. The influence of austenitizing and tempering temperature on the hardness and fracture toughness of hot-worked H11 tool steelJournal of Materials Processing Technology 178 (2006) 328–334.

4 AMERICAN SOCIETY FOR TESTING AND MATERIALS, Philadelphia. ASTM E-18 - 17 ; Standard Test Methods for Rockwell Hardness of Metallic Materials.

5 AMERICAN SOCIETY FOR TESTING AND MATERIALS, Philadelphia. ASTM A-561-08; Standard Practice for Macroetch Testing of Tool Steel Bars.

6 AMERICAN SOCIETY FOR TESTING AND MATERIALS, Philadelphia. ASTM E-407-07; Standard Practice for Microetching Metals and Alloys.