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Effect of Q&P Process on 0.15C-MnSi Steels

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Abstract: The present study is focused on analyzing the effect of Mn amount on two experimental steel compositions, specially designed for Q&P (Quenching and Partitioning), 0.15C-2.5Mn-1.5Si and 0.15C-3Mn-1.5Si without significant contribution of Al. Two-Step Q&P thermal treatments were performed at laboratory scale in a quenching dilatometer Bähr DIL805A/D. The fractions of retained austenite were evaluated by X-ray diffraction techniques. The mechanical properties of the Q&P samples were evaluated, a strong dependence of strength, uniform elongation and strain hardening values on process parameters has been found. Higher uniform elongation were related to higher residual austenite contents. The 0.15C-3Mn-1.5Si steel showed systematically the largest mechanical values with respect to the 0.15C-2.5Mn-1.5Si steel.

Key words: Steels, Q&P, mechanical properties.

Nomenclature

Q&P	Quenching and partitioning
M_s	Martensite start
M_f	Martensite finish
QT	Quenching temperature
PT	Partitioning temperature
VIM	Vacuum induction melting

1. Introduction

The so called Q & P (Quenching and Partitioning) steels belong to a family of third generation family of advanced high strength steels where increasing strength values can be attained at significant ductility values (as high as 1,200 MPa and 20% respectively). Quenching and partitioning, as a new processing concept, was firstly proposed in 2003 [1].

The process involves (Fig. 1):

(1) Quenching of austenite to a temperature (QT) between the Ms (Martensite start) and Mf (Martensite finish) temperatures with the formation of martensite and untransformed retained austenite.

(2) Isothermal partitioning treatment at a temperature PT to allow diffusion pf carbon from supersaturated martensite into retained austenite in order to stabilize the latter phase at room temperature.

(3) A significant body of research into microstructural evolution during Q&P process can be found in the literature (e.g. [2-4]). A comprehensive review of the mechanisms controlling microstructural changes during the application of the Q&P process has been recently published [3]. On the other hand, only a few publications are focused on the mechanical properties of the Q&P steels and microstructure-properties relationship in these materials. For the Q&P processing, it is very important to choose the most efficient alloying strategy for the material. Alloying elements must be capable of:

- Suppressing carbide precipitation during Q&P processing;
- Allowing diffusion of carbon into retained austenite that stabilizes retained austenite at room temperature;

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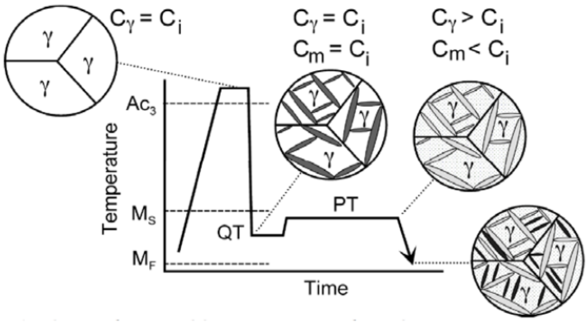


Fig. 1 Schematic diagram of the Q&P process, producing austenite/martensite microstructures, as appropriate, from homogeneous austenite. C_i, C_γ and C_m represent the carbon contents of the initial alloy, austenite, and martensite, respectively, and QT and PT are the quenching and partitioning temperatures respectively [2].

- Providing solid solution strengthening to achieve high strength and good ductility in the material.

It has been shown that silicon and aluminum, can be utilized for stabilization of retained austenite at room temperature [5-7] and their relation to mechanical properties is reported [8-10]. The present study is focused on analyzing the effect of Mn amount on two experimental steel compositions, specially designed for Q&P, 0.15C-2.5Mn-1.5Si and 0.15C-3Mn-1.5Si, without significant contribution of Al.

2. Experimental Setup

Two steel chemical composition were considered as reported in Table 1.

Two 80 kg ingots cast at the CSM vacuum induction plant (VIM) have been then hot rolled on a pilot plant down to 4.8 mm after reheating at 1,250 °C, with 900 °C finish rolling temperature and 560 °C coiling temperature. 2-Step Q&P thermal treatments have been performed at laboratory scale in a quenching dilatometer Bähr DIL805A/D. The fractions of retained austenite have been evaluated by X-ray diffraction techniques. The tensile properties and microstructure of the Q&P samples have been evaluated on dilatometric specimens. Microstructures have been examined by a 300 keV JEOL 3200FS–HR TEM (Transmission electron microscope) on thin foils.

3. Experimental Results

Hot rolled materials have been submitted to a series of 2-Step Q&P treatments.

Partitioning times have been selected as a function of the partitioning temperature in order to have similar diffusion paths for carbon.

Results in term of UTS values show that (Fig. 2):

- UTS is reduced with partitioning time.
- Steel A shows lower strength values (below 1,200 MPa) than Steel B.

Table 1 Steel chemical composition of the considered materials (mass, %).

	C, %	Mn, %	Si, %	Al, %
Steel A	0.15	2.5	1.5	0.03
Steel B	0.15	3.0	1.5	0.03

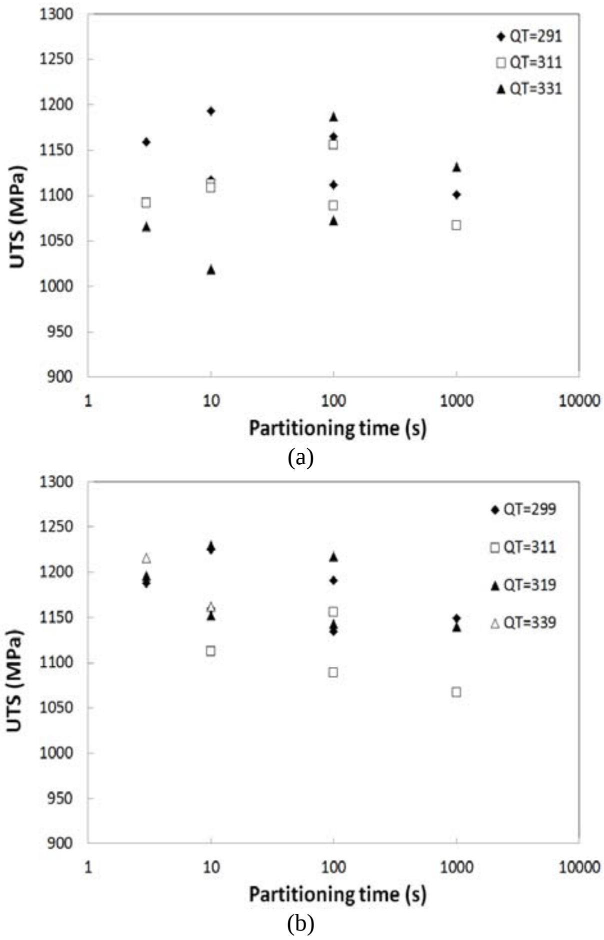
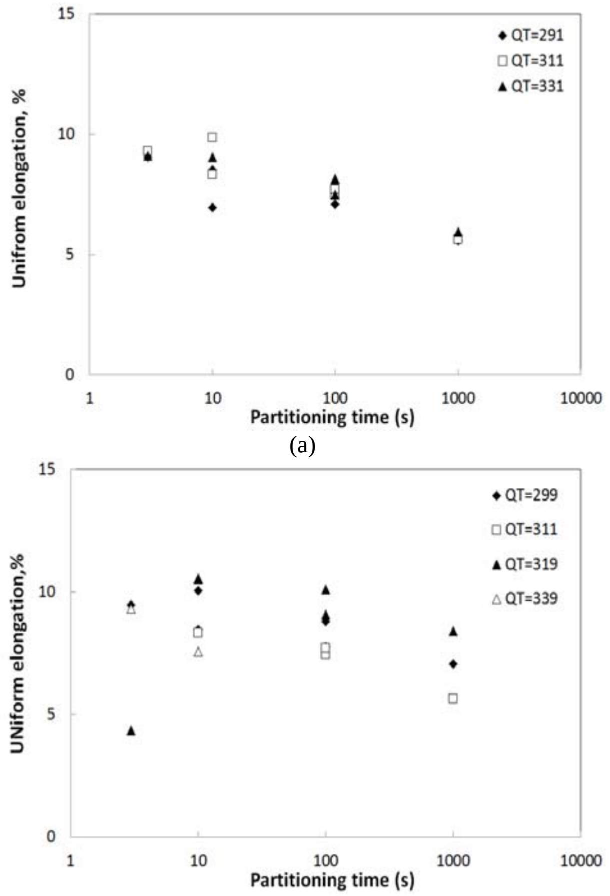


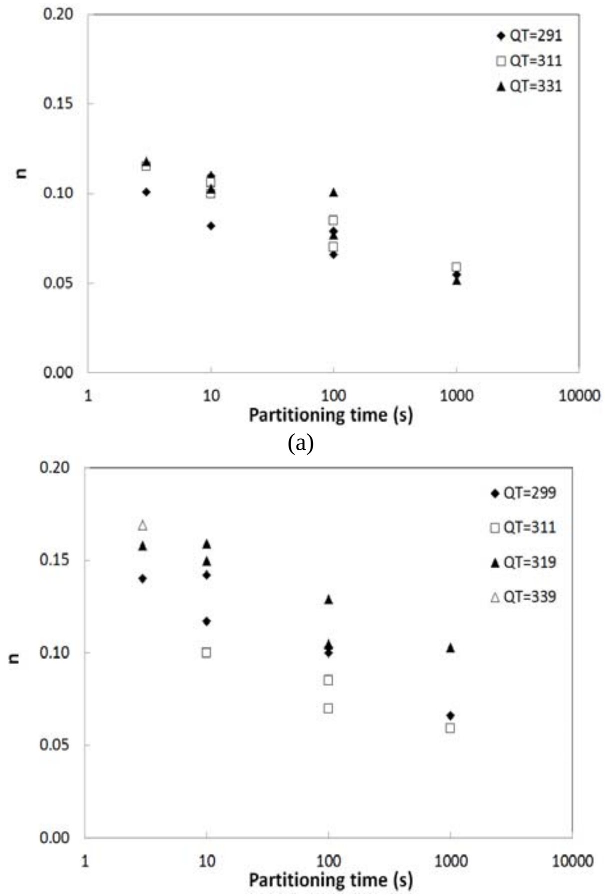
Fig. 2 Effect of partitioning time on UTS for Steel A (a) and Steel B (b).



(a)

(b)

Fig. 3 Effect of partitioning time on uniform elongation for Steel A (a) and Steel B (b).



(a)

(b)

Fig. 4 Effect of partitioning time on n-values for Steel A (a) and Steel B (b).

In terms of ductility both steels present similar tendency. In particular, uniform elongation is reduced with increasing partition time and with decreasing the partition temperature, irrespective of the quenching temperature. Larger values of ductility are obtained for Steel B (Fig. 3).

Moreover, results in Fig. 4 show that:

• The strain hardening exponents (n-values) systematically decrease with increasing partition time and with decreasing partition and quench temperature.

• For Steel B n-values as high as 0.17 are obtained, while in case of Steel A they are systematically lower.

A higher content of residual austenite is found in the case of higher uniform elongation (Fig. 5).

The best mechanical properties are obtained by quenching to 335 ºC and then partitioning at 350 °C for 100 s for both steels.

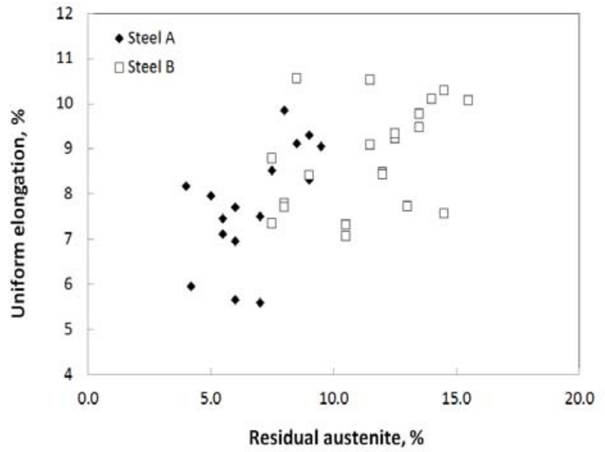


Fig. 5 Relationship between uniform elongation and volume fraction of residual austenite.

In this process condition the steels show a microstructure constituted by martensite, residual austenite (about 10%) and bainite formed during cooling (Figs. 6 and 7). The presence of bainite is due

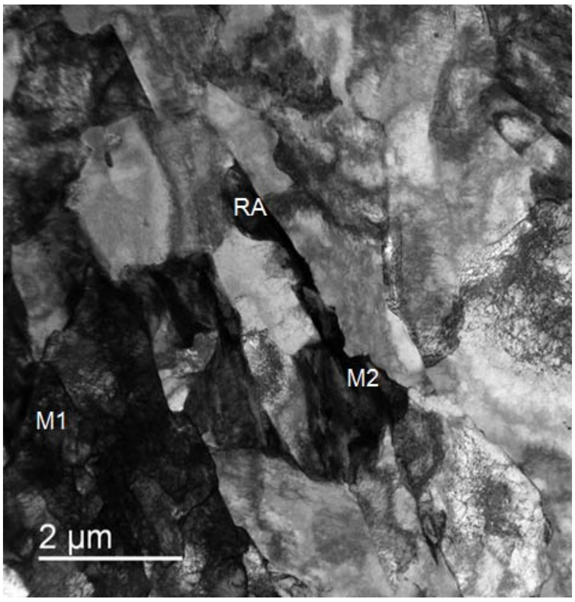


Fig. 6 Steel A: microstructure after quenching to 335 ºC and partitioning at 350 °C for 100 s.

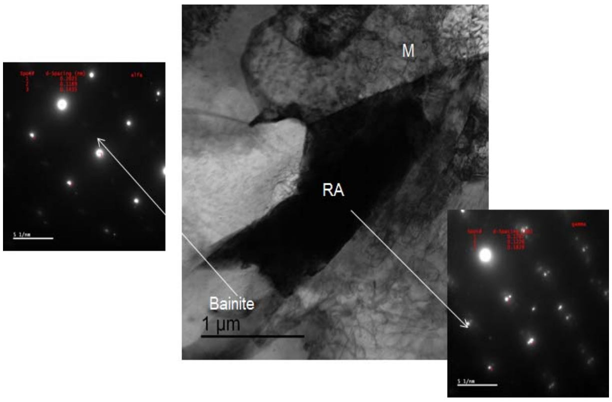


Fig. 7 Steel B: microstructure after quenching to 335 ºC and partitioning at 350 °C for 100 s.

to the low C content (0.15%), which does not allow a fully martensitic transformation during cooling.

4. Conclusions

The dependence of mechanical properties on Q&P process parameters has been evaluated for CMnSi steels with two different Mn contents. The results show a strong dependence of strength, uniform elongation and strain hardening values on the process parameters. Uniform elongation has been found to increase with increasing the content of residual austenite. The 0.15C-3Mn-1.5Si steel shows systematically the largest mechanical values with respect to the 0.15C-2.5Mn-1.5Si steel.

Acknowledgments

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References

[1] Speer, J. G., Matlock, D. K., De Cooman, B. C. and Schroth, J. G. 2003. "Carbon Partitioning into Austenite after Martensite Transformation." *Acta Materialia* 51: 2611-22.

[2] Rizzo, F., Martins, A. R., Speer, J. G., Matlock, D., Clarke, A. and De Cooman, B. 2007. "Quenching and Partitioning of Ni-Added High Strength Steels." *Materials Science Forum* 539-543: 4476-81.

[3] Santofimia, M. J., Nguyen-Minh, T., Zhao, L., Petrov, R., Sabirov, I. and Sietsma, J. 2010. "New Low Carbon Q & P Steels Containing Film-like Intercritical Ferrite." *Materials Science and Engineering A* 527: 6429-39.

[4] De Moor, E., Speer, J. G., Matlock, D. K., Kwak, J. H. and Lee, S. B. 2011. "Effect of Carbon and Manganese on the Quenching and Partitioning Response of CMnSi Steels." *ISIJ International* 51: 137-44.

[5] Masek, B., Jirkova, H., Hauserova, D., Kucerova, L. and Klauberova, D. 2010. "The Effect of Mn and Si on the Properties of Advanced High Strenghth Steels Processed by Quenching and Partitioning." *Materials Science Forum* 654-656: 94-7.

[6] Cao, W., Wang, C., Shi, J. and Dong, H. 2010. "Application of Quenching and Partitioning to Improve Ductility of Ultrahigh Strength Low Alloy Steel." *Materials Science Forum* 654-656: 29-32.

[7] Zhao, H., Shi, J., Li, N., Wang, C.-Y., Hu, J. and Hui, W. et al. 2011. "Effects of Si on the Microstructure and Mechanical Property of Medium Mn Steel Treated by Quenching and Partitioning Process." *Chinese Journal of Materials Research* 25: 46-50.

[8] Hauserova, D., Duchek, M., Dlouhya, J. and Novy, Z. 2011. "Properties of Advanced Experimental CMnSiMo Steel Achieved by QP Process." *Procedia Engineering* 10: 2961-6.

[9] Zhao, C. and Tang, D. 2011. "Effect of Heat Treatment Process on Microstructure and Properties in Low Carbon Si-Mn Q&P Steel." *Advanced Materials Research* 233-235: 1009-13.

[10] Wang, Y., Zhou, S., Guo, Z. and Rong, Y. 2010. "Study of a Novel Ultra-High Strength Steel with Adequate Ductility and Toughness by Quenching-Partitioning-Tempering Process." *Materials Science Forum* 654-656: 37-40.