Effect of quenching & partitioning process on a low carbon steel

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Abstract

Aim of this paper is to analyze the effect of manganese percentages on steel compositions. Laboratory as cast materials, in particular designed for Quenching and Partitioning process (Q&P), are here considered. The considered steel chemical composition was that of a 0.15C with 1.5Si, two different Mn contents and with no significant Al content. Two-Step Q&P heat treatments were carried out in laboratory by means of dilatometric tests. X-ray diffraction measurements have been carried out aimed to assess the retained austenite volume fraction. The tensile properties of the quenched and partitioned materials were analyzed. Results showed a marked dependence of strength, ductility and strain capacity values on heat treatment conditions. In the case of higher austenite contents, higher uniform elongation values were found. Higher tensile properties were found in the case of higher Mn steel with respect to the lower Mn one. The main novelty of this paper consists in applying Q&P to low carbon (low hardenability steel) showing the effect of such a process on mechanical properties of steels usually adopted for automotive applications. Copyright © 2017 VBRI Press.

Keywords: Metals, partitioning, tensile properties.

Introduction

High strength steels (HSS) with significant percentages of residual austenite were designed in last years, due to market requests [**1, 2**]. Considering the case of steel coils, just as an example, the transformation induced plasticity (TRIP) phenomenon following carbon-enriching of metastable retained austenite is beneficial since during deformation contributes to formability and impact toughness behavior. In gear for example, the presence of austenite in microstructure provides tolerance to damage when fatigue applications are considered. If applications are taken into account requiring high strength and/or thicker sections, the presence of retained austenite provides improvement in fracture resistance. In the same way, ductile cast iron materials are characterized by improved properties combinations when microstructure is formed by fine ferritic grains together with carbon-stabilized austenite.

Steel materials characterized by the presence of elevated high carbon austenite at room temperature, are usually manufactured by low temperature transformation. Final microstructure in this case is a "carbide-free bainite" consisting of bainitic ferrite laths packets containing austenite islands within the laths. Usually Silicon or Aluminum additions are carried out with the aim to obstacle Fe_3C formation in cooling, usually joint to bainite nucleation. In the last years, a new process, named quenching and partitioning, has been designed for the manufacturing of steel materials characterized by tempered martensite and residual austenite microstructure. In this materials, a key role is played by the carbon partitioning, through diffusion processes, between low temperature tempered martensite and residual austenite. In particular Q&P materials belong to the third generation of Advanced High Strength Steels (AHSS). In this case, increased strength is achieved together with high ductility values (20 % uniform elongation in the case of strength in the range 1150-1200 MPa). Q&P, as a new concept for steel materials processing, was firstly presented in [**3**].

The process is characterized by the following three stages (**Fig. 1**):

1. Rapid cooling of austenite down to QT temperature. Such temperature needs to be in the range M_s<QT<M_f (where M_s indicated the start of martensitre transformation and M_f the completion of the same transformation, with the

formation of martensite and untransformed retained austenite.
2. Heating up to PT temperature and staying at such temperature. During this process stage the carbon diffusion is the only microstructural active process, moving from martensite into austenite finalized at austenite stabilization at room temperature.

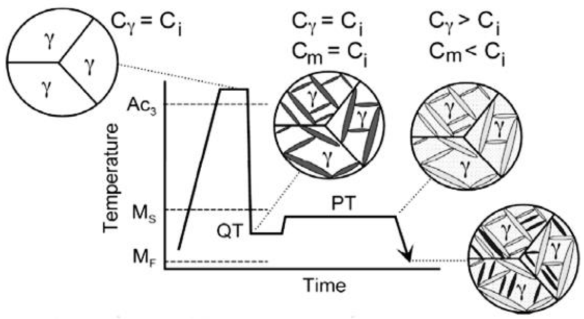

Fig. 1. Q&P treatment (scheme) leading to austenite/martensite microstructure. C_i, C_γ and C_m are the carbon contents of steel before tratment, austenite, and martensite [**2**].

Many papers have been published related to microstructural evolution during quenching and partitioning (e.g. [**3-5**]). Initial analysis of the Q&P treatment focused on a 0.35%C steel containing, 1.3%Mn and 0.74%Si where martensite formation during cooling was easier since favored by high steel hardenability [**5**]. In last year's Gerdemann studied the response to Q&P heat treatment of a 0.60%C material added with 2% of silicon. He compared results to those achieved by standard heat treatments normally performed on such steel [**6**]. In particular, he austenitised at 900 °C, quenched down to temperatures 150°C<T<210°C, then heated up to 250°C<T<500 °C thus activating the partitioning stage of the process. Specimens were then rapidly cooled down to RT. The quenching temperatures were chosen in order to form various austenite volume fractions in the matrix, thus allowing to estimate their effect on final steel properties. A review of the mechanisms driving microstructural evolution during quenching and partitioning heat treatment is reported in [**4**].

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:

- preventing the formation of Fe_3C therefore allowing the carbon to be available for austenite enrichment and stabilization;
- stabilizing austenite through carbon diffusion;
- providing solid solution strengthening with following higher tensile properties and elevated material ductility.

It is well known that Si and Al [**7-10**] can be added to stabilize austenite at RT [**11-16**]. It is clear from the above consideration that the higher the carbon content, the easier to apply such a process (in order so stabilize austenite) and many papers have been published in last ten years about the applicability of Q&P process to medium/high carbon steels.

Main novelty of this paper consists in applying Q&P to low carbon (low hardenability steel) showing the effect of such a process on mechanical properties of steels usually adopted for automotive applications. This paper focuses on the manganese effect on two experimental materials, thought for quenching and partitioning.

Experimental

Materials

The below materials chemical composition were proposed (**Table 1**).

Table 1. Chemical composition of the proposed steels (mass, %).

	C, %	Mn, %	Si, %	Al, %
Steel 1	0.148	2.45	1.45	-
Steel 2	0.147	3.05	1.45	-

Two ingots were manufactured by means of VIM. Ingots have been then machined and hot worked to 4.8 mm thick plates after heating at 1250 °C, finish rolling temperature 895 °C, coiling 560 °C. 2-Step quenching and partitioning was carried out in lab using dilatometric techniques.

Characterization

The presence of residual austenite was verified by X-ray technique. The mechanical characterization and microstructure assessment of the quenched and partitioned specimens was carried out based on dilatometric specimens. Microstructures have been analyzed by Transmission Electron Microscope (TEM) operating at 300 keV using thin foils methodology. Specimens were prepared according to [**17**].

Results and discussion

Quenching and partitioning treatments have been performed on hot rolled materials. Treatments have been designed with partitioning times selected as a function of PT in order to have the same carbon diffusion.

Mechanical properties

Ultimate tensile strength (UTS) values are reported in **Fig. 2** and show that:

- UTS decreases as partitioning time increases.
- Lower UTS (<1150 MPa) are found in Steel 1 if compared to Steel 2.

If ductility is considered, both Steel 1 and Steel 2 show the same behavior. In particular, uniform elongation decrease if partition time increases and if partition temperature is lowered.

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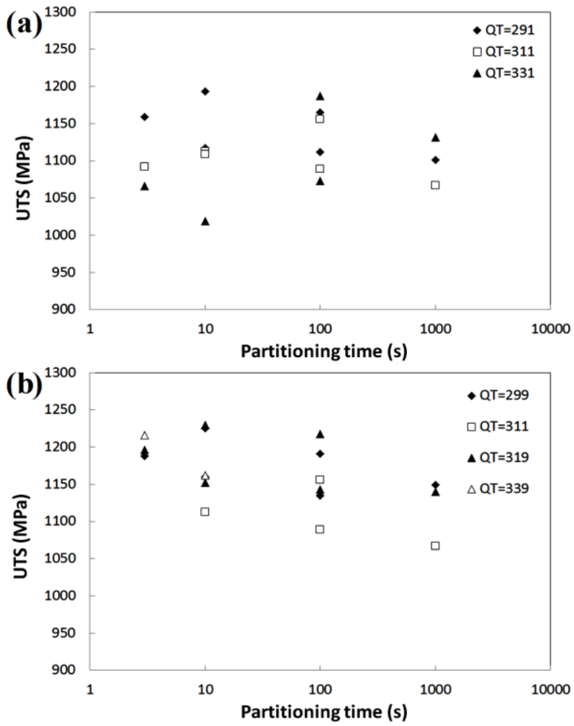

Fig. 2. UTS versus partitioning time (Steel 1 (i) and Steel 2 (ii) (partitioning temperature=340 °C).

This is not affected by the quenching temperature. Higher uniform elongation values are detected in Steel 2 (**Fig. 3**).

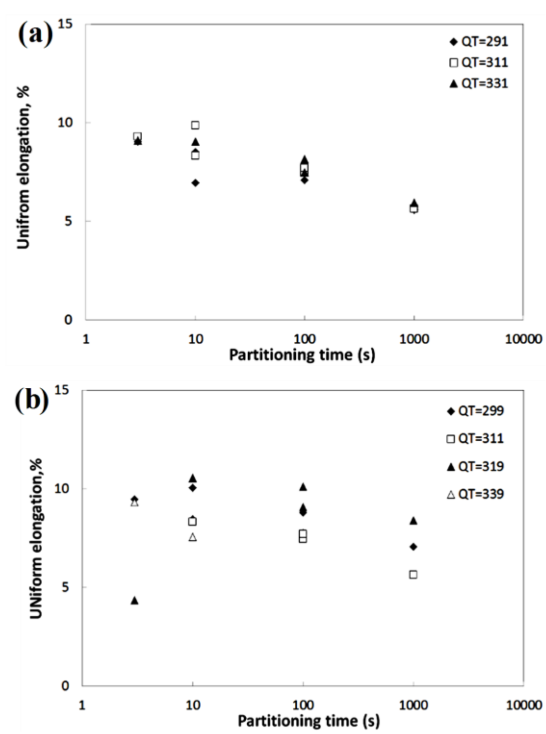

Fig. 3. Ductility versus partitioning time (Steel 1 (a) and Steel 2 (b) (partitioning temperature=340 °C).

Moreover, from results in results in Fig.3 it appears that higher ductility is related to higher content of carbon enriched austenite **[3-5]** (**Fig. 4**).

Microstructure

The optimum strength/elongation combination is in both materials achieved after cooling down 335 ºC and then heating and mainating at 350 °C. After these processes condition the microstructure in both materials is formed by martensite and carbon enriched austenite (about 10%) which appeared to remain stable after quenching (**Fig. 5a**). Some fresh bainite formed during cooling (**Fig. 5b**) is detected in the case of Steel 2 (lower Mn content).

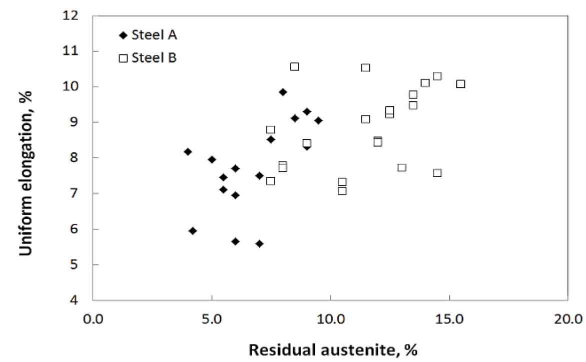

Fig. 4. Ductility versus retained austenite volume fraction.

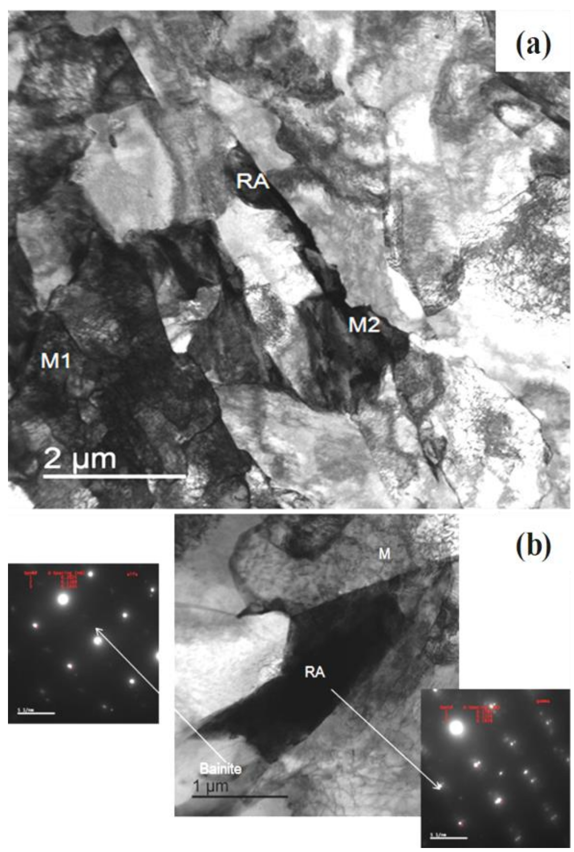

Fig. 5. Steel 2: quenched microstructure. a) QT=335 ºC, PT=350 °C; b) QT=335 ºC, PT= 350 °C.

Conclusion

Main novelty of this paper consists in applying Q&P process to low carbon (low hardenability steel) showing the effect of such a process on steel properties fin the case of materials usually adopted for automotive applications. This paper focuses on the manganese effect on two experimental materials, thought for quenching and partitioning. In the case of higher austenite contents, higher uniform elongation values were found. Higher tensile properties were found in the case of higher Mn steel with respect to the lower Mn one.

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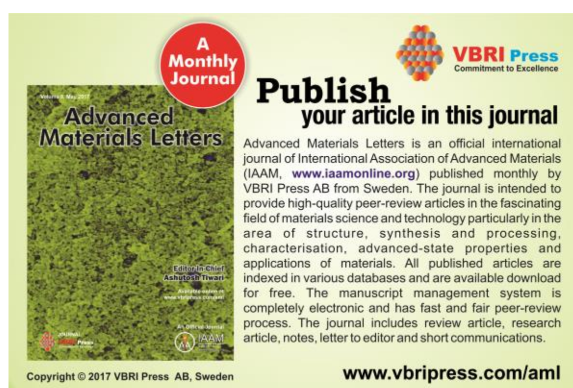

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