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Analysis of the effect of interrupted quenching on microstructure of high carbon steels for forgings

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Abstract

The present study is focused on analyzing the effect of the interrupted quenching followed by a partitioning process in a high carbon steel 0.50C-1.50Mn-0.40Si-2.00 Cr without significant contribution of Al. Thermal treatments were performed at laboratory scale in a quenching dilatometer Linseis R.I.T.A RL78. The fractions of retained austenite were evaluated by scanning electron microscope. The temperature for the interrupted quenching phase was evaluated based on the Koistenen and Marburger equation (adapted to the 0.50C steel) and the result highlights a correlation between the chosen different temperature of quenching and the fraction of retained austenite formed during the quenching step of the process. Copyright © 2017 VBRI Press.

Keywords: Steels, microstructure, retained austenite.

Introduction

Steel is one of the primary materials in use today, however, even after century of research, innovative methods are being discovered and exploited to produce steel with enhanced properties [**1, 2**]. One of such recent discovery has been called Quenching and Partitioning (Q&P) allowing a multiphase microstructure consisting of retained austenite stabilized to room temperature, and a harder martensitic phase. This combination is prospected to form a new generation of high strength, formable sheet steel well suited to the demands of automotive industry. In particular Q&P steels belong to the third-generation family of Advanced High Strength Steels where increasing strength values can be attained at significant ductility values (as high as 1200MPa and 20% respectively). Quenching and Partitioning, as a new processing concept, was firstly proposed in 2003 [**3**]. The process involves (**Fig. 1**):

1. Quenching of austenite to a temperature (QT) between the martensite start (M_s) and martensite finish (M_f) 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.

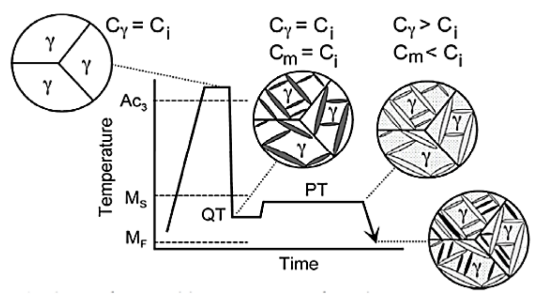

Fig. 1. Schematic diagram of the Q&P process, producing austenite/martensite microstructures, as appropriate, from homogeneous austenite. C_i, C_γ and C_m represent the carbon contents of the initial alloy, austenite, and martensite, respectively, and QT and PT are the quenching and partitioning temperatures,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

A comprehensive review of the mechanisms controlling microstructural changes during the application of the Q&P process has been reported in [**3**]. The question of how best to predict the fraction of martensite formed for a given undercooling below the martensite start temperature has been answered by the work of Koistinen and Marburger (K-M) [**4**]. By quenching four different iron-carbon alloys to three different temperatures, they created sufficient data to identify a relationship between the level of undercooling below the martensite start temperature, and the fraction of material transformed from austenite to martensite. The thermal martensite starts to form at quenching to the martensite start temperature, Ms. However, further undercooling is required to form more martensite since the elastic and plastic accommodation of the transformation strains require an additional driving force. The fraction of martensite is critical to the performance of steels since it affects mechanical properties such as strength and toughness, directly, and a precise description of the fraction of martensite with undercooling can be utilized in process design or optimization of the properties. For instance, such a model is valuable in the design of TRIP steels or dual-phase steels [**5**]. The Koistinen-Marburger equation dictates that “at any temperature below Ms, a constant fraction of the austenite remaining will be transformed by a given additional temperature decrement”. The fraction of martensite, f, is expressed as:

$$f = 1 - \exp(\beta(M_s - T_q)) \quad (1)$$

where β is a material constant and T_q is the temperature to which the material is quenched. The drawback of the K-M equation is that it has a parabolic shape Up to now, the Q&P process has been mainly devoted to steels for automotive applications, where a good combination of strength and ductility is required, with very low carbon steels. Some preliminary efforts have been devoted to the study of steels with medium carbon content, which were also reported in this Journal [**6**]. In all these cases, high Si steels were considered (Si>2%), since Si inhibits carbides formation thus favoring austenite stabilization. On the other hand, it is well known that Si addition has other negative impacts on steel properties (for example in terms of oxidation). The main novelty of this paper consists in applying Q&P to high carbon steels with low Si content on materials usually adopted for forgings analyzing the effect of four interrupted quenching temperatures on the amount of retained austenite. The laboratory results have a direct industrial application since during industrial quenching of large forged ingots some regions of the component undergo an interrupted quenching. This work therefore allows to predict the effect of such interrupted quenching on the final microstructure of a forged component.

Materials

The steel reported in **Table 1** has been considered.

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

	C, %	Mn, %	Si, %	Cr, %
Steel A	0.50	1.50	0.40	2.00

2-Step Q&P thermal treatments have been performed at laboratory scale in a quenching dilatometer Linseis R.I.T.A RL78.

Characterization

The fractions of retained austenite have been evaluated by scanning electron microscope (SEM). The microstructure of the Q&P samples has been evaluated on dilatometry specimens. Microstructures have been examined by microscope equipped with Zeiss Axio ICc1 camera. All the dilatometry treatments were evaluated in conformity with ASTM A1033:04. After the Q&P process the dilatometry specimens were mounted under heat and pressure with a hot mounting press and in order to obtain a highly reflective surface that is free from scratches and deformation, the specimens were carefully grinded and polished with an automatic grinder using six different grain size paper from 120 grits to 4000 grits. The samples were polished up to diamond paste with t grain size dimension of 3 μm and 1 μm. The samples were etched with 4% nital.

Results and discussion

Design of the process

The a-dimensional β parameter (which is different for different steels) is an unknown term in the K-M equation (1), needing therefore to be validated on the considered steel. First of all was hypothesized that at M_f temperature the martensite volume fraction of formed after the quenching process was f_v=0.99.

Table 2. Temperature of martensite start (Ms) and martensite finish (M_f).

	M_s [°C]	M_f [°C]
Steel A	290	110

Replacing this value (M_f, T_q and *f,* present in Table 2) in the K-M equation it is possible to calculate β :

$$\beta = \frac{\ln(1-f)}{(M_s - T_q)} = -0.025$$

After evaluated β, the curve that represent the trend of *f* in function of T_q is calculated and reported in **Fig. 2**.

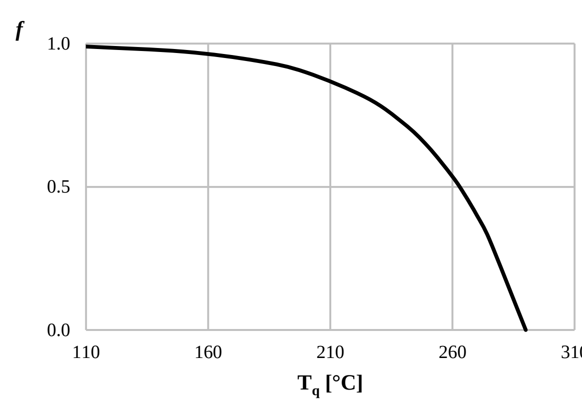

Fig. 2. Diagram of the fraction of martensite formed after the quenching process in function of the quenching temperature.

The quenching process was interrupted at four temperatures, showed in the **Table 3** and corresponding to different calculated f_v values according to (1).

Table 3. Interrupted quenching temperatures and calculated martensite volume fraction.

T_q [°C]	f_v
270°C	0.40
240°C	0.72
200°C	0.90
150°C	0.97

The material has been submitted to a series of 2-Step Q&P treatments, where partitioning times and temperature have been selected as a function of the CCT diagram of steel A and the four-different temperature of Q&P process were selected using the Koistenen and Marburger equations adapted to steel A.

The temperature chosen for the partitioning step was 330°C (40°C above the Ms temperature) and the samples was held at that temperature for 600 seconds. The experimental trials were designed as following (**Fig.3**):

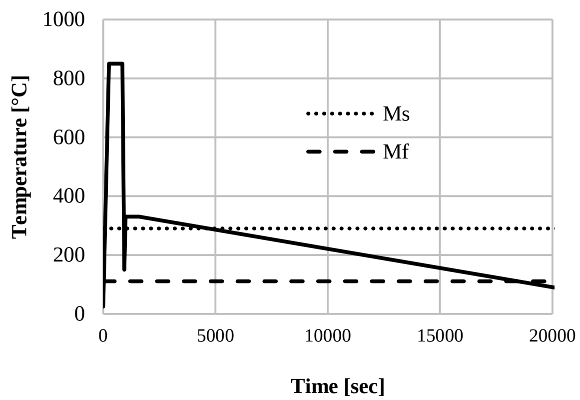

Fig. 3. Schematic diagram of the Q&P process set at dilatometer Linseis R.I.T.A RL78.

1. Heating from room temperature (25°C) to 850°C (3,3 °C/s).
2. Austenitization at 850°C for 600 second.
3. Rapid cooling from 850°C to four different temperatures (cooling rate of 100°C/s):
   a. 270°C
   b. 240°C
   c. 200°C
   d. 150°C
4. Heating from the previous temperature (heating rate of 3,3°C/s) to 330°C:
5. Holding at 330°C for 600 seconds;
6. Slowly cooling to room temperature (cooling rate of 0,013 °C/s).

SEM micro-analysis

The SEM micro-analysis has allowed to investigate the effect of the Q&P heat treatments on microstructure. It is worth of mentioning (**Fig. 4**) that the decreasing interrupt quenching temperature generates a multiphase microstructure consisting of retained austenite (black phase) stabilized to room temperature, and a martensitic phase (white phase) in line with the Koistenen and Marburger equations adapted to steel A.

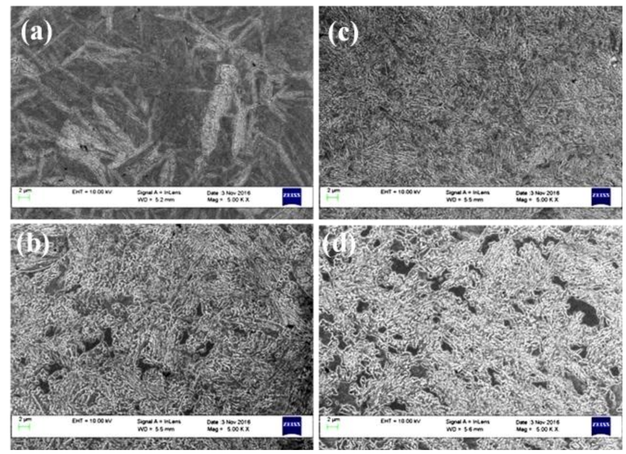

Fig. 4. SEM micrographs at 5000x magnification. Particular of samples where the quenching process was interrupted at 270°C (a), 240°C (b), 200°C (c) and 150°C (d).

Conclusion

The main conclusion of this paper consists in applying Q&P to high carbon steels with low Si content on materials usually adopted for forgings analyzing the effect of four interrupted quenching temperatures on the amount of retained austenite. The laboratory results have a direct industrial application since during industrial quenching of large forged ingots some regions of the component undergo an interrupted quenching. This work therefore allows to predict the effect of such interrupted quenching on the final microstructure of a forged component.

Reference

1. Ceschini, L.; Marconi, A.; Martini, C.; Morri, A.; Di Schino, A.; *Mater. Des*., **2013,** *45*, 171.
   DOI: 10.1016/j.matdes.2012.08.063
2. Di Schino, A.; Kenny J.M.; Salvatori, I.; Abbruzzese, G.; *J. Mater. Sci*., **2003**, *38*, 4725.
   DOI: 10.1016/S1359-6454(03)00059-4
3. Speer, J.G.; Matlock, D.K.; De Cooman, B.C.; Schroth, J.G.; *Acta Mater*., **2003**, *51*, 2611.
4. Koistenen, D.; Marburger, A; *Acta Metallurgica*, **1959,** *7*, 60.
   DOI: 10.1016/0001-6160(59)90170-1
5. Pastore, E.; Hovolenko, O.; Negri, S.D.; Ienco, D.; Macciò, M.; Pinasco, A.; Saccone, M.; La Metallurgia italiana, **2011**, *33-42*, 4.
6. Di Schino, A.; Di Nunzio P.E. Cabrera J.M..; *Advanced Materials Letters*, in press.