

Research Article

## Effect of Quenching and Partitioning Process in Carbon Steels

K Harsha Vardhan<sup>†\*</sup>, V Shubhanyu<sup>‡</sup>, U Raj Kumar<sup>†</sup> and D Sai Abhishek<sup>†</sup>

<sup>†</sup>Department of Mechanical Engineering, Vidya Jyothi Institute of Technology, Hyderabad, T.S., India

Accepted 01 May 2017, Available online 02 May 2017, Vol.7, No.3 (June 2017)

### Abstract

*In order to improve our living standards in all aspects, it is an endeavor to find suitable structural materials for efficient functioning with an assurance of catastrophic-free failures and abundant availability of such materials at relatively low cost. Since the humanity, started using iron (and steel) for various applications from that age. As a result, until now, more than 2500 variety of steels have been made. As our understanding of metals and alloys goes deeper and deeper with modern testing tools, we are able to improve properties like strength and ductility and at the same time reducing the weight of the structural steel. Demand for such material is becoming mandatory in industries like sheet metal industry and automotive industry, where the transport vehicles have to be designed to meet the stringent requirements like the safety of human beings in case of collision with other vehicle or any obstacle and emitting less dangerous gasses and thus protect the environment. Keeping this in mind, first-generation Advanced High-Strength steels (1G-AHSS) was produced but it involved hot stamping and reheating sheet. To overcome such treatment at higher temperature, second-generation AHSS (2G-AHSS) was created with alloying elements. Though this steel was made with high strength and good formability, it requires high levels of alloying elements, which are very expensive. Nowadays, the industry is making all efforts to make 3G-AHSS to overcome disadvantages, associated with previous generation of steels, using new concept, namely quenching and partitioning (Q & P) to provide necessary balance between strength, formability and cost.*

**Keywords:** Advanced High Strength Steels, hot stamping, Reheating, formability, Quenching and Partitioning.

### 1. Introduction

Iron's allotropic transformation are the source of the diverse forms of steel microstructures. Earth is enriched with raw material of Iron and Iron-ores, produced by many nuclear reactions. The conventional structures found in steel are Ferrite, Cementite, Pearlite, Austenite, Ledeburite, Martensite, and Bainite.

For many application purposes, we need both Hardness and Ductile nature of steels whose final properties are achieved by many developed Heat Treatment processes. The steels namely, AHSS and UHSS have a unique role in development in future references. There are three main types of manufacturing AHSS. They include Intercritical processing for TRIP steels, Quenching and Partitioning, Long Time Austempering.

The first process is used for TRIP steels (Transformation Induced Plasticity steels) which comprises of chemical composition:

|            |   |             |
|------------|---|-------------|
| Carbon%    | - | 0.12 - 0.55 |
| Manganese% | - | 0.2 - 2.5   |
| Silicon%   | - | 0.4 - 1.8   |

\*Corresponding author: K Harsha Vardhan

Now, it is suitable for most of other steels that have the composition with other alloying elements such as Copper, Chromium, Magnesium, with considerably high weight percentage embedded in certain steels. Because of these alloying elements, there may be insignificant properties that may obtain after Heat Treatment.

The second process namely, Quenching and Partitioning falls into the category of Multi-phase steels. This process exhibits best combination of Hardenability and ductility nature of steels. This process is more suitable for Low alloy TRIP steels. So it is regarded as best method for basis of producing 3-G AHSS.

The third process requires long annealing times, which is time consuming and requires very high temperature assisting Heat Treatment. Therefore, it is not suitable for Industrial purpose.

Hence, among different manufacturing processes of AHSS, Quenching and Partitioning is most suitable for Low alloyed steels, which improves hardness, ductility and toughness at considerably low costs. Q & P include two-step Heat Treatment.

#### 1.1 Austenitisation

First, the steel sample is Austenitized at considerably high temperature over Ac<sub>3</sub> (temperature for transformation of Ferrite into Austenite) and hold for

approximately one hour, to get pure, homogeneous Austenite phase ( $\gamma$ ). During this stage, the sample possess high ductility and low hardness with FCC structure. The Austenitisation temperature is also dependent on amount of Martensite to be formed after quenching (Wijanarko, 2016).

### 1.1.1 Predicting the parameters required for Austenitisation

Empirical formulae have been developed to predict Austenitisation as a function of chemical composition. Andrews used data from different steel compositions to determine formulae for  $A_{c3}$ ,  $A_{c1}$  and  $A_{c2}$  temperatures. These are the austenite-equilibrium finish temperature and the austenite-critical start and finish temperatures respectively. The  $A_c$  temperatures are dependent on heating rate, while the  $A_e$  temperatures are representative of true equilibrium conditions (Andrews, 1965).

### 1.1.2 Structural changes during Austenitisation

During Austenitisation the transformation in steel from the ferritic, Body Centered Cubic (BCC) structure to the austenitic, Face Centered Cubic (FCC) structure occurs. Cementite and other carbides decompose, and the carbon released is held within austenite at interstitial sites.

## 1.2 Quenching of sample

After that, the steel sample is quenched at temperature between Martensite start temperature ( $M_s$ ) and Martensite finish temperature ( $M_f$ ). The more amount of Martensite is formed in steel sample, if the quench temperature ( $T_q$ ) is very less, compared to  $M_s$  Temperature. The quench severity of sample is given by

$$\text{Quench severity} = (h / 2k)$$

$h$  = convective heat transfer coefficient ( $W/m^2 K$ )

$k$  = thermal conductivity ( $W/m K$ )

The Martensite start temperature ( $M_s$ ) plays an important role to acquire the hard and brittle Martensite phase partially in sample with also untransformed Austenite phase present in it. The partial Martensite phase is obtained in sample because of its instability at temperature below  $A_{c1}$  (temperature for transformation of Pearlite to Austenite). Different scientists have proposed different formulae for calculation of  $M_s$  temperature:

$$1) M_s = 539 - 423 C - 30.4 Mn - 17.7 Ni - 12.1 Cr - 7.5 Mo \text{ (Andrews, 1965)}$$

$$2) M_s = 561 - 474 C - 33 Mn - 17 Ni - 17 Cr - 21 Mo \text{ (Steven and Haynes, 1956)}$$

The fraction of Austenite remaining after Quenching is given by

$$V_\gamma = \exp \{-1.10 * 0.01 * (M_s - T_q)\}$$

(Koistinen and Marburger, 1959)

Where  $M_s$  = Martensite start temperature

$T_q$  = Quench temperature

The main parameters that influence Quench severity are:

- Quench medium The quench media generally used are water, oil and Nitrate salts like Sodium Nitrate ( $NaNO_3$ ), Potassium Nitrate ( $KNO_3$ ), and Chloride salts like Barium chloride ( $BaCl_2$ ), Sodium chloride ( $NaCl$ ), Potassium chloride ( $KCl$ ), and  $NaOH$ ,  $KOH$  depending upon the working temperature range. Quenching in salt bath results in reduced cracks and distortions, helps in acquiring desired lower temperature of sample.
- Quench Temperature The quench severity is more for sample, if quench temperature is very low. The cooling rate of sample from Austenitisation should be at least  $450^\circ C/sec$  to get desired properties for any steel while quenching.
- Agitation Sample in the salt bath should be agitated for some period in order to get required quench severity. If the agitation period is more, then quench severity is also more. The propeller type agitators are used, with proper assistance to avoid any surface oxidation and decarburization.
- Quench time The sample should remain in salt bath for at least 5 seconds to disperse the vapors uniformly throughout the quench medium, that are produced after quenching. Non-uniform dispersion may lead to change in microstructure and produces distortions.

The martensitic transformation is diffusion less, and so the chemical compositions of the parent and product phases are identical. In contrast, the equilibrium (ferrite/pearlite/carbide) structures form via a diffusional reconstructive process involving many individual random atom displacements. Therefore, in diffusional transformations, time is required to achieve the equilibrium state, and chemical inhomogeneity can occur.

### 1.2.1 Structural changes during martensite formation

The structure of martensite is universally accepted to consist of a Body-Centered arrangement of iron atoms, in which the carbon atoms preferentially occupy interstitial sites on only one axis, thus giving rise to a distortion from the Body-Centered-Cubic (BCC) to the Body-Centered-Tetragonal (BCT) structure.

After Quenching, Steel is partitioned above  $M_s$  Temperature to allow carbon diffusion from Hard Martensite to Austenite for the enrichment of untransformed Austenite phase in final stage. The

amount of retained Austenite depends on the Partition temperature, Partition time, and Partition medium. By the reduction of untransformed and retained Austenite grain size, the strength of the steel sample is maintained with more volume fraction of Austenite phase. Kinetics of Q & P. minimizes the dislocations and voids during Martensitic transformation.

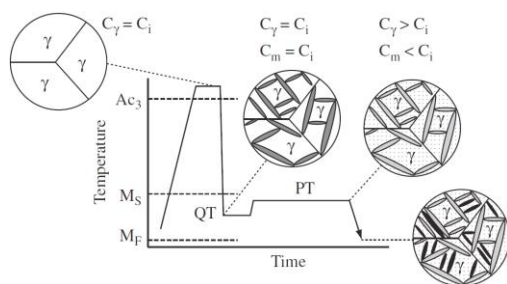
### 1.3 Partitioning of sample

The Partition temperature mostly effects the shape of martensite structure in sample. The Lath structures of Martensite is clearly observed in final structure at low partition temperature, thus allowing high strain energy in martensite. The Partition temperatures for Low alloyed steels are 350°C, 400°C and 450°C. The higher the partition temperature, more the reduction in martensite strain energy and grain size of retained Austenite phase will be more. The sample is then normalized to room temperature to reduce thermal stresses.

In iron, self-diffusion (and substitutional diffusion) is dependent upon a suitably located vacancy, and the vibrational movement of surrounding atoms. For interstitial diffusion, the requirement is similar in that there must be a suitably located vacant interstitial site, and the matrix atoms must move sufficiently to allow the interstitial atom to pass through. The size difference between carbon and iron atoms (and other substitutional alloying elements) is such that carbon atoms are accommodated within interstitial sites.

#### 1.3.1 Carbon distribution in retained austenite

The efficiency with which an ideal partitioning stage is able to prevent transformation to martensite during final quenching is dependent upon effective homogenization of carbon within the austenite. While the situation of steady-state diffusion is readily solvable by Fick's First Law, the conditions existing during partitioning are significantly more complex for two reasons. Firstly, the diffusion is not steady state because there is a continuous depletion of carbon from the martensite and corresponding increase in carbon concentration in the austenite. Secondly, the diffusion coefficient of carbon in austenite varies according to its own concentration (Smith, 1953)



Schematic illustration of the Q&P process for producing of austenite-containing microstructures.  $C_i$ ,

$C_\gamma$ ,  $C_m$  represent the carbon contents of the initial alloy, austenite, and martensite, respectively. QT and PT are the quenching and partitioning temperatures (Speer & A. M. Streicher, Quenching and partitioning: a fundamentally new process to create high strength trip sheet microstructures, 2003)

### 1.4 Polishing and Etching

After Quenching and Partitioning, the sample should be grinded by belt surface grinder and hand polishing was made using a series of grids namely 120 P, 220 P, 400 P, 500 P, 600 P, 800 P, 1000 P, and fine polishing is made using grids of 1/0, 2/0, 4/0.

After that, Disc polishing should be made using Alumina powder ( $\text{Na}_2\text{O} \cdot 11\text{Al}_2\text{O}_3$ ) and cleansed with water. Next, Diamond paste is used with disc polishing under fine velvet cloth.

Now, the sample is observed under electron microscope by adjusting the Magnification to get desired and visible microstructure.

To observe the Grain size, the sample is etched with Nital (Ethanol - 100ml and Nitric acid 5-10 ml with concentration of 69-72%).

## 2. Research on Quench and Partitioned Steels

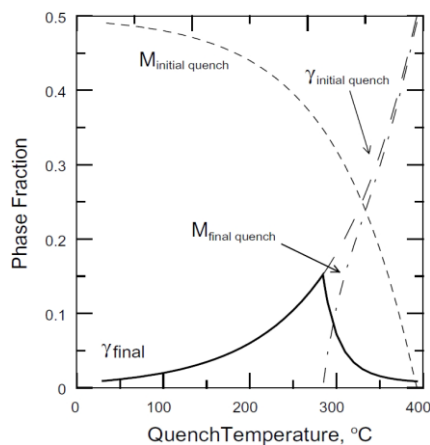
Although it is considered that some heat treatment processes may have done, or do currently follow the Q&P temperature/time profile, the intentional use of a heat treatment process to bring about the multiphase Q&P microstructures and associated mechanical properties that have been achieved in recent years is thought to be a new development. (Edmonds, 2006). A number of studies have now been published examining Q&P over carbon ranges from low-carbon TRIP steels to medium-carbon bar steels; although it is well to bear in mind that it is the carbon concentration of the quenched austenite which is important, which in the case of austenite carbon enrichment is not the same as that of the bulk steel.

## 3. Predicting the outcome of a Q&P heat-treatment process

The first report of Q&P as a 'fundamentally new process' was made in 2003 (Speer & A. M. Streicher, 2003). This initial report focused on the thermodynamic driving forces for carbon partitioning, and the means of suppressing carbide precipitation. A theoretical model was also included (see Figure 1.17) for predicting the phase fractions after quenching and partitioning via use of the Koistinen- Marburger relationship (Koistinen & Marburger, 1959).

Predicted Q&P microstructure components for experimental steel containing 50% intercritical ferrite, vs. quench temperature, assuming full partitioning prior to final quenching to room temperature. The solid bold line gives the final austenite fraction at room temperature. Dashed lines represent the austenite and

martensite (M) present at the initial quench temperature, and the additional martensite formed during the final quench to room temperature. It should be noted that  $\alpha_{IC} + M_{\text{initial quench}} + M_{\text{final quench}} + \gamma_{\text{final}} = 1$  and  $\alpha_{IC} = 0.5$  in this example (Speer & A. M. Streicher, 2003)



## Conclusion

The effect of Quenching and Partitioning in steels is observed.

- Relation between phase transformations and the quenching temperature is found. Relation between partitioning temperature and the phase transformations is established.
- The extent of changes to the hardness of steels due to the Q&P process.
- Q & P process also maintain work hardening of heat-treated steels at considerable strain. This process is most suitable for low alloy TRIP steels caused by the higher volume fraction of Retained Austenite in them.
- This process is applied for equilibrium and semi-equilibrium phases of steel to obtain highly desirable mechanical properties.

## Acknowledgement

The authors express their thanks to Head of the Mechanical Engineering Department, Principal, Director and Correspondent of Vidya Jyothi Institute of Technology, Aziz Nagar, Hyderabad for the help and support extended towards this work.

## References

- Andrews, K. W. (1965). Empirical formulae for the calculation of some transformation temperatures. *Journal of the Iron and Steel Institute*, Vol. 203(July), 721-727.
- De Moor, E. (2009). Assessment of quenching and partitioning as a fundamentally new way of producing advanced high strength martensitic steel grades with improved ductility. University of Gent.
- Edmonds, D. V. (2006). Quenching and partitioning martensite - A novel steel heat treatment. *Materials Science and Engineering*, Vol. A438-A440, 25-34.
- Koistinen, D. P., & Marburger, R. E. (1959). A general equation prescribing the extent of the austenite-martensite transformation in pure iron-carbon alloys and plain carbon steels. *Acta Metallurgica*, 59-60.
- Lee, S. K. (2005). Effect of Austenite Grain size on Ms of Low Alloy steel.
- Smith, R. P. (1953). Diffusivity of carbon in iron by the steady-state method. *Acta Metallurgica*, Vol. 1(September), 578-587.
- Speer, J. G., & A. M. Streicher, e. a. (2003). Quenching and partitioning: a fundamentally new process to create high strength trip sheet microstructures. *Austenite Formation and Decomposition*, Proceedings of a Symposium held at the Materials Science & Technology Meeting. Chicago, Illinois, USA: Minerals, Metals & Materials Society.
- Wijanarko, W. (2016). Q & P variation on retained Austenite fraction in AISI 4140. 11.
- Samatham Madhukar, Birudala Raga Harshith Reddy, Rontala Saketh Reddy And Dr. V.V. Satyanarayana , 2017. Experimental Investigation of Effect Of Heat Treatment on Nose Radius of Insert And Temperature at Cutting Area in Turning Of Titanium (Grade International Journal of Mechanical Engineering & Technology (Ijmet). Volume:8,Issue:3,Pages:34-41
- Samatham Madhukar , Paaka Vidyanand Sai , Sumith Kumar and Dasari Jagath Prakash (2016), Experimental Investigation on Effect of HeatTreatment on Mechanical Properties of Titanium Alloy (Ti-6Al-4V) , International Journal of Current Engineering and Technology, Vol.7, No.1 (Feb 2017) , pp-238-242