



# Study of microstructural evolution and mechanical properties exhibited by non alloyed ductile iron during conventional and stepped austempering heat treatment

J.L. Hernández-Rivera\*, R.E. Campos Cambranis, A. de la Garza

Facultad de Ingeniería-Instituto de Metalurgia, Universidad Autónoma de San Luis Potosí, Sierra Leona 550, Lomas 2ª sección, C.P. 78210, San Luis Potosí, Mexico

## ARTICLE INFO

### Article history:

Received 16 March 2011

Accepted 18 June 2011

Available online 25 June 2011

### Keywords:

C. Heat treatments

E. Mechanical

F. Microstructure

## ABSTRACT

It was evaluated the microstructural and mechanical response that a non alloyed ductile iron (DI) presented when was subjected to Conventional Austempering (CA) and Stepped Austempering (SA) heat treatments. X-ray Diffraction (XRD) quantification techniques demonstrated to be the more reliable method for monitoring phase transformations taking place during both CA and SA. When CA was applied some intercellular areas remain untransformed even for long time, however when samples were subjected to SA those untransformed areas disappeared and instead finer ausferrite was found. Additionally mechanical properties values obtained from tensile and impact tests confirmed that for all times used, SA was superior to the CA.

© 2011 Elsevier Ltd. All rights reserved.

## 1. Introduction

The use of DI has increased constantly since its introduction in the market due to the relatively low production costs coupled with excellent mechanical properties. After that, the development of austempered ductile iron (ADI) in the 1970s promoted a new impulse for the application of DI thanks to its excellent combination of good ductility at high strength, high fatigue strength and fracture toughness, and superior wear resistance [1,2]. Because of these advantages, ADI has been used to replace forged steel components in many applications such as crankshafts, gears, bit of drill and rolls and also in many structural and wear resistant applications in automotive industry, defense and earth moving machineries [3–5].

The starting material for ADI should be high quality nodular cast iron with high nodule counts and nodularity. The attractive properties of ADI are related to its unique microstructure that consists of ferrite needles and High Carbon Stabilized Austenite (HCSA), aggregate that are commonly referred as ausferrite. It is important to point out that this resultant aggregate differed from the austempered steels where the microstructure consists of ferrite and carbide, and ought to this reason the product of austempering reaction in DI is not common to be referred as bainite. On the other hand, small amounts of alloying elements such as nickel, molybdenum and copper are generally added to ADI to provide sufficient hardenability in order to avoid pearlite formation during quench-

ing since it has been evidenced that this phase decreases considerably the mechanical properties.

During austempering, two-stage phase transformation reaction takes place in ADI [6,7]. In the first one, high temperature austenite (HTA) decomposes into ferrite and HCSA. If the casting is held at the austempering temperature for too long time, a second reaction takes place, which causes further decomposition of the HCSA into ferrite and carbides (commonly cementite). The presence of this phase makes the material more brittle and that is why this second reaction must be avoided during austempering process. There is also the possibility that residual HTA could transform into martensite when ADI is cooled to room temperature and the time period for the first stage has not been completed, so it also diminishes the maximum attainable properties.

The time period between the completion on the first reaction and the onset of the second is termed as process window. It is now well established [8,9] that the best combination of mechanical properties (tensile strength and ductility) is obtained in ADI after the completion of the first reaction but before the onset of the second one. When ADI is austempered at lower temperatures such as 260 °C, it has finer ausferrite and it results in higher yield and tensile strength but lower ductility. On the other hand, when ADI is austempered at higher temperatures than 370 °C, it has coarser ausferrite and this reduces the yield and tensile strengths but imparts higher ductility.

With the objective to obtain a better combination of tensile strength, toughness and ductility some research groups have evaluated modifications to CA cycle. Bayati et al. [10] used SA to overcome the decrease in the mechanical properties promoted by the residual HTA observed in the last to freeze segregated regions in alloyed ADI. By using the second step a lower temperature (T2) compared with the first temperature (T1), these authors were able to complete

\* Corresponding author. Present address: Stuttgart Center for Electron Microscopy, Max Planck Institute for Intelligent Systems, Heisenbergstraße 3, 70569 Stuttgart, Germany. Tel.: +49 711 689 3639/3647.

E-mail addresses: [jose.hernandez@cimav.edu.mx](mailto:jose.hernandez@cimav.edu.mx), [jlhernandez@mf.mpg.de](mailto:jlhernandez@mf.mpg.de) (J.L. Hernández-Rivera).