FRACTURE TOUGHNESS OF HIGH STRENGTH DUCTILE CAST IRON PRODUCED BY QUENCHING AND PARTITIONING PROCESS

Andre Melado[1]*, Estefano Vieira[1], Arthur Nishikawa[2], Wanderson Silva[3] and Helio Goldenstein[4]

[1] Department of Metallurgy, Espirito Santo Federal Institute, Vitória - ES, Brazil.
[2] Department of Materials Science and Engineering, Delft University of Technology, Delft, Netherlands
[3] Department of Materials Engineering, Santa Catarina Federal University, Blumenau - SC, Brazil.
[4] Department of Metallurgical and Materials Engineering, University of São Paulo, São Paulo - SP, Brazil.
* *Presenting Author email: andre.melado@ifes.edu.br*

Abstract

The quenching and partitioning process (Q&P), used to produce advanced high strength steels (AHSS), has also proved to be a route to obtain ductile cast irons with high strength and good toughness. This article uses the chevron-notch methodology to analyze the fracture toughness, under different microstructures, of a commercial ductile cast iron after quenching and partitioning treatment.

1. Introduction

Quenching and partitioning (Q&P) is a heat treatment process to obtain high strength steels with multi-phase microstructures consisting of martensite and substantial amounts of carbon-stabilized retained austenite, along with small fractions of carbide, and varying quantities of bainitic ferrite. The process consists of a two-steps heat treatment. After austenitization (full or partial), the steel is quenched to a temperature between Ms and Mf to produce a controlled mixture of martensite and austenite. Then, in the so-called partitioning step, the material is isothermally held at a partitioning temperature above quenching temperature to allow the carbon partitioning from martensite into remaining austenite. Generally, a high concentration of Si is added to the steel composition to control cementite formation. The bainitic transformation is another factor that acts in the carbon supply, which the formation of bainitic ferrite occurs and the carbon diffuses to the remaining austenite. Thus, austenite is stabilized and retained in the final cooling to room temperature. Due to the metastable nature of the retained austenite, transformation-induced plasticity (TRIP), i.e., deformation-induced transformation of austenite to martensite, may occur during deformation or fatigue crack propagation, per example.

Due to the high levels of Si present in nodular cast irons, it makes it a candidate for the application of Q&P process. In this work, the Q&P was applied on ductile cast iron and the fracture toughness, using the chevron-notch methodology (K_{ICV}), was evaluated. Different microstructures were formed through the variation of treatment parameters such as quenching temperature (QT) and partitioning temperature (PT), under different times.

2. Results

The microstructure of nodular cast iron after quenching and partitioning (Q&PDI) consists of martensite plates, bainitic ferrite lath and austenite retained (form of blocks and films between the bainitic ferrite). Small carbides were also found inside the martensite plates.

Tensile test showed that the material presented ultimate tensile strength (UTC) values higher than 1700Mpa. Considerable elongation values were obtained, as in the condition QT=170°C and PT=375°C which presented 9% elongation with UTC of 1450Mpa.

The fracture toughness (K_{ICV}) of the Q&PDI reached values of 55 MPa.m$^{1/2}$.

The variation of the heat treatment parameters produced different microstructures in the material (different fraction of retained austenite, martensite, bainitic ferrite and formation of carbides). This directly influenced the response to the fracture toughness test of the material.

The results obtained of K_{ICV} showed that materials treated with partitioning temperature of 375°C (PT=375°C) presented better results than those treated at lower temperatures (PT= 300°C). The reduction in carbon content in supersaturated martensite is greater for PT=375°C and this reduces its brittleness, which was also confirmed in an impact test. Part of this carbon from martensite was partitioned to retained austenite, another part precipitated as small carbides.

The samples with the highest amount of retained austenite showed better values of fracture toughness. Figure 1 shows the relationship of the product of the volumetric fraction and carbon content in the retained austenite with the fracture toughness results of the material.

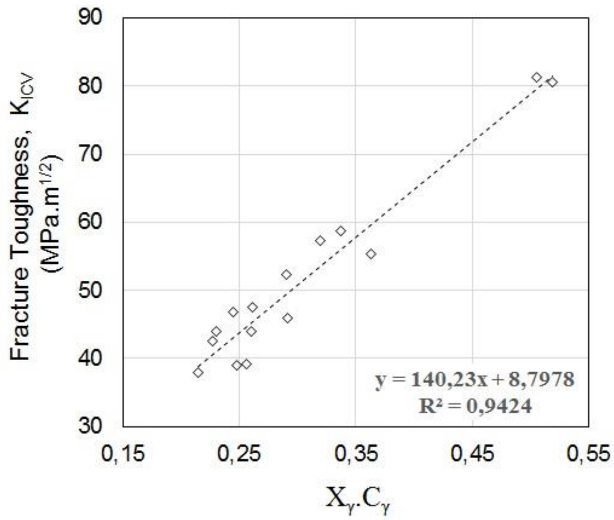

Fig.1 – Influence of volumetric fraction and carbon content in the austenite (Xγ.Cγ) on the fracture toughness of the Q&PDI and ADI.

Stress concentration ahead of the crack tip can lead to the transformation of retained austenite into martensite (deformation-induced transformation). Thus, a part of the energy supplied to the sample during the test is used for the transformation of martensite from austenite. Furthermore, this transformation produces compressive stresses at the crack tip. Compression tests showed a reduction in the volumetric fraction of austenite retained in Q&PDI with increasing strain.

The fracture surface analysis was performed to verify the active fracture mechanisms. For PT=300°C, the samples showed a brittle fracture (cleavage type). Samples treated with PT=375°C showed areas with predominance of dimples, characteristic of a ductile fracture.

3. Conclusions

The Queching and Partitionig (Q&P) heat treatment proved to be a route for the production of nodular cast irons with high strength combined with good toughness. Materials that had a higher volumetric fraction of austenite retained in their microstructure showed a better fracture toughness properties.

Acknowledgements

Authors are grateful to the Brazilian government agencies for research development: CNPq-Conselho Nacional de Desenvolvimento Científico e Tecnológico, FAPES-Fundação de Amparo à Pesquisa-ES-Brasil, Capes-Coordenação de Aperfeiçoamento de Pessoal de Nível Superior and FINEP-Financiadora de Estudos e Projetos for their collaboration.