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## Damaging micromechanisms in an as cast ferritic and a ferritized ductile cast iron

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### Abstract

Mechanical behavior and damaging micromechanisms in Ductile Cast Irons (DCIs) are strongly effected by matrix microstructure (e.g., phases volume fraction, grains size and grain distribution) and graphite nodules morphology peculiarities (e.g., nodularity level, nodule size, nodule count, etc.). The influence of the graphite nodules depends on both the matrix microstructure and the loading conditions (e.g., quasi-static, dynamic or cyclic loadings). According to the most recent results, these graphite nodules show a mechanical properties gradient inside the graphite nodules, with the graphite elements – matrix debonding as only one of the possible damaging micromechanisms.

In this work, two different ferritic DCIs were investigated (a ferritic matrix obtained from as-cast condition and a ferritized matrix) focusing on the damaging micromechanisms in graphite nodules due to tensile stress. Specimens lateral surfaces were observed using a Scanning Electron Microscope (SEM) during the tests following a step by step procedure.

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### Introduction

Ductile cast irons (DCIs) are characterized by the presence of free graphite with a nodule shape obtained by means of a chemical composition control instead of extended annealing treatment of white irons as in malleable irons. Thanks to this peculiar graphite shape, instead of lamellae as in grey cast iron, DCIs are able to combine the castability of

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gray irons with toughness of carbon steels. Because of their versatility and their higher performances at lower cost (compared to steels with analogous performances) DCIs are widely used in different applications. Nowadays, DCIs are mainly used in the form of ductile iron pipes (for transportation of raw and tap water, sewage, slurries and process chemicals), in safety related components for automotive applications (gears, bushings, suspension, brakes, steering, crankshafts) and in more critical applications as containers for storage and transportation of nuclear wastes. DCIs matrix controls mechanical properties and matrix names are used to designate spheroidal cast iron types, Jeckins (1993), Ward (1962), Labreque (1998). The most common DCIs grades commercially available are:

- Ferritic DCIs show good ductility and impact properties, with a tensile strength that can be considered equivalent to the values offered by low carbon steel.
- Pearlitic DCIs are characterized by higher strength values, good wear resistance and moderate ductility.
- Ferritic-pearlitic have intermediate properties between ferritic and pearlitic ones.

Focusing on graphite elements shape, a very high nodularity is strongly recommended. The peculiar morphology of graphite elements in ductile irons is responsible of DCIs good ductility and toughness. Graphite nodules act as “crack arresters”, with a consequent increase of toughness, ductility and crack propagation resistance. DCIs main damage micromechanism is often identified as voids growth corresponding to graphite nodules and numerous studies provided analytical laws to describe growth of a single void, depending on the void geometries and matrix behaviour, Liu (2002), Liu (2004), Bonora (2005), Iacoviello (2008): as a consequence, spheroids role is completely neglected. Considering almost fully ferritic DCIs, Berdin (2001) proposed that these DCIs should be essentially considered as porous materials, graphite nodules being considered as voids in an elastic–plastic matrix. Microcracks in graphite nodules were also observed, but their presence was not considered as important. Damage main micromechanism was identified with graphite–matrix debonding, and all the other mechanisms were considered as negligible. Recently, Di Cocco (2010 and 2014), especially considering ferritic matrix, the role of the graphite–matrix debonding was reduced, considering the evident contribution to the DCI damage of supplementary damaging micromechanisms. Among them:

- An “onion-like” damage mechanism: nodule shield debonds from nodule core by means of a ductile mechanism; this mechanism is probably connected to a different mechanical behaviour between the nodule “core” (obtained directly from the melt) and the carbon shield (obtained by means of solid diffusion during cooling).
- Radial and transversal cracks initiation and propagation: this damage mechanism is usually more evident corresponding to graphite elements with a reduced roundness; some radial cracks can be also identified in nodule cores, probably corresponding to graphite solidification nucleation sites (e.g., non metallic inclusions like MgS or CaS);

In this work, differences between the damaging micromechanisms in a as cast ferritic and in a ferritized DCIs were investigated by means of step by step tensile tests. Lateral specimens surfaces were analysed by means of Scanning Electron Microscope (SEM) observations during the tests.

## 2. Investigated material and experimental procedure

Two DCIs were considered with good nodularity:

- An as cast ferritic DCI (chemical composition in Tab. 1; nodularity is higher than 85%);
- a ferritized DCI (chemical composition in Tab. 2; nodularity is higher than 95%).

The second DCI was ferritized by an annealing heat treatment, consisting of an austenitizing stage at 920 °C for 4 h, followed by a slow cooling down to room temperature inside the furnace, Fernandino (2015).

Mini tensile specimens, characterized by a length×width×thickness equal to 25×2×1mm, were metallographically prepared and were underwent to tensile tests using a tensile holder (Fig.1). The following step by step procedure was adopted, Di Cocco (2010):

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