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The SEM study of ADI material embrittlement in water and hydrogen environment

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Austempered ductile iron (ADI) is advance material produced by austempering of ductile iron. Due to unique microstructure of ADI material, known as ausferrite (mixture of high carbon enriched, stable, retained austenite and ausferritic ferrite), its possess an excellent combination of mechanical properties, such as: high strength, ductility and toughness together with good wear, fatigue resistance and machinability. Consequently, ADI materials are used increasingly for many wear resistant and tough engineering components in different sectors including automotive, trucks, construction, earthmoving, agricultural, railway, etc [1, 2].

However, in recent years it is noticed that ADI materials in contact with water and other liquids exhibits a drop of tensile properties, that is, decrease in strength and even more critically, ductility [3-5]. This embrittlement phenomenon could potentially lead to catastrophic failure in practical applications. Furthermore, the embrittlement phenomenon is revertible [3]. After removing from water and drying, specimens revert their previous tensile properties. There are several explanations for degradation of the tensile properties. The most common is hydrogen embrittlement [3]. However, Masud *et al* [4] suggested that this process is not an electrochemical phenomenon and that H atoms are not responsible for the embrittlement. Furthermore, Caballero *et al* [5] also reported that hydrogen is not involved in embrittlement of ADI and that the water is substance which embrittle the ADI. As there is still some unknowns about influence of hydrogen on the embrittlement phenomenon further study is necessary.

For that reason, in this study a tensile test (EN 10002) of ADI materials in water and gaseous hydrogen environment was performed. The two different grades of ADI were used. The ADIs were produced from unalloyed ductile iron by austenitisation at 900°C for 2 hour, followed by austempering at 300 or 400°C for 1 hour. The microstructure was examined by “Leitz-Orthoplan” light microscope, while fracture mode has been examined by SEM JEOL JSM 6460LV, at 20kV.

The light micrographs of the ADI microstructure are given in Figure 1. The graphite spheroidisation was more than 90%, with average graphite volume fraction of 10.9%, nodule size of 25 to 30 μm and nodule count of 150 to 200 per mm^2, Figure 1a. The austempering at 300°C/1h produce ADI material with high strength but lower ductility, while 400°C/1h produced ADI with lower strength but with higher ductility, Table 1. This difference in mechanical properties is due to different morphology of obtained microstructures [1, 2]. The microstructure of both samples is fully ausferritic consisting of mixture of ausferritic ferrite and carbon enriched retained austenite. The increase of transformation temperature from 300 to 400°C changes the ausferritic morphology, from needle-like (Figure 1b) to more plate-like (Figure 1c), and amount of retained austenite from 16 to 31.4%, respectively. The results of tensile test (Table 1) in different environments showed that the ADI material exhibits the most pronounced decrease of tensile properties in the water. Testing in the hydrogen atmosphere showed that there is also some reduction of mechanical properties. This decrease is less pronounced compared to testing in the water. The SEM analysis of embrittled specimens revealed brittle fracture mode at a small specimens surface area, Figure 2. The rest of the surface exhibits mostly ductile fracture mode with some quasi-cleavage, Figure 3. The brittle fracture area at the surface indicates that the fracture was initiated in that zone. However, the appearance of brittle fracture is not typical for this type of ADI material. Partially, the fracture looks like as result of fatigue crack growth, with appearance of randomly oriented striations lines stretching from free specimens surface or free surface around graphite nodules, Figure 4a. This appearance could be attributed to the cyclic chemisorption of hydrogen into narrow region beneath specimens surface. Thus, causing embrittlement, then brittle fracture and finally, new free surface where chemisorption might start again. The high magnification of transgranular cleavage fracture in brittle zone can be seen in Figure 4b.

Based on obtained results it could be summarized that primary effect on ADI material embrittlement has hydrogen. Furthermore, embrittlement is more pronounced in liquid environments than in gaseous. The chemisorption of hydrogen atoms into the material surface cause the formation of brittle zone which acts as a weak place for the fracture nucleation.

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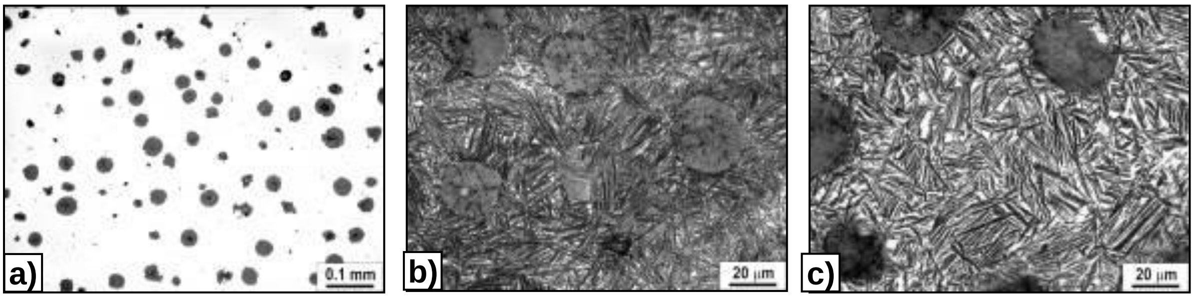

Figure 1. Microstructure of ADI: a) polished surface; b) 300°C/1h, c) 400°C/1h

Material	Proof strength, $R_{p0,2\%}$ [MPa]	Tensile strength, R_m [MPa]	Elongation, A_5 [%]	Environment
As-cast	326	473	22.2	dry
ADI-300°C/1h	1395	1513	3.8	dry
	-	1180	-	water
	1283	1504	4.5	hydrogen gas
ADI-400°C/1h	757	1042	14.2	dry
	727	838	3.5	water
	721	978	9.2	hydrogen gas

Table 1. Tensile properties in dry condition, water and hydrogen gas

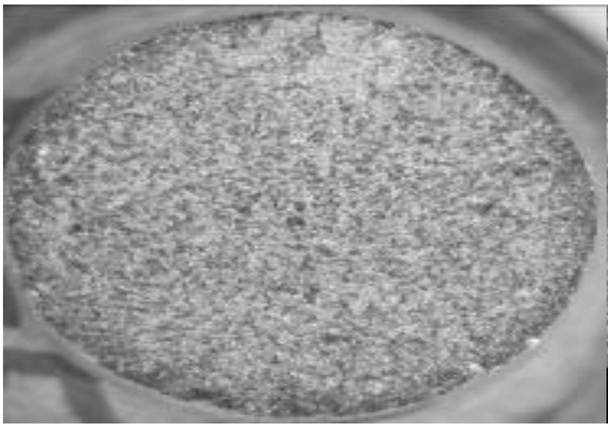

Figure 2. Fracture zones (arrow-embrittlement zone)

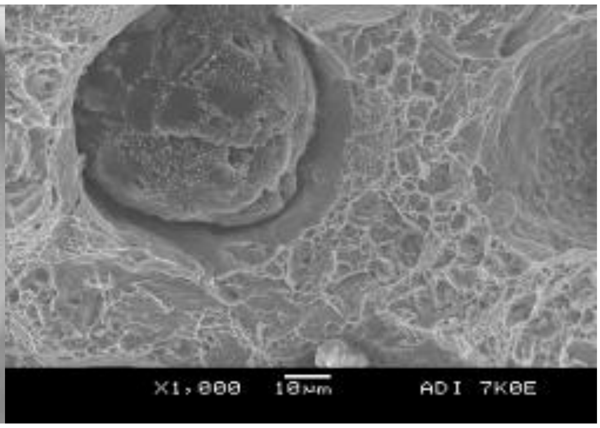

Figure 3. Fracture mode of ductile zone

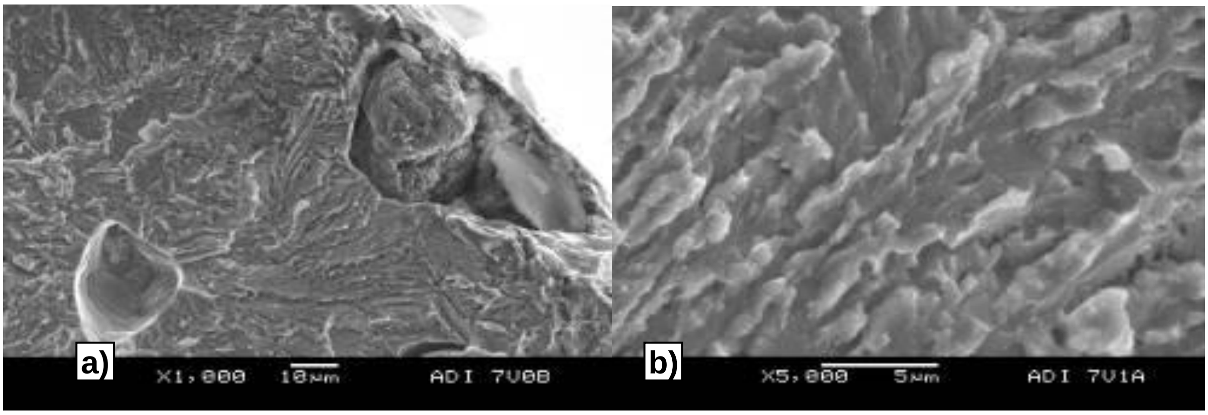

Figure 4. Fracture mode of embrittlement zone