The SEM study of crack nucleation and propagation path in alloyed ADI materials

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The ADI (Austempered Ductile Iron) is a real advanced material, produced by austempering of conventional ductile iron. The ADI have a unique ausferrite microstructure, which is a mixture of ausferritic ferrite, and carbon enriched retained austenite [1-3]. Due to tailoring of microstructure by heat treatment, the ADI can have a remarkable combination of high strength, ductility and toughness together with good wear, fatigue resistance and machinability [3]. Furthermore, ADI has a 10 % lower weight and up to 30 % lover production cost when compared to forged steel. For these reasons, ADI material is increasingly used for many engineering parts in different sectors including automotive, trucks, construction, earthmoving, agricultural, railway and military [3]. As the ADI might be subjected to extreme forces which could cause fracture during use or manufacturing process (machining or plastic deformation), the study of ADI material fracture behavior under such conditions is of great importance. In view of this, in present work, crack nucleation and propagation path in two alloyed ADI materials having different microstructures were studied.

Ductile irons alloyed with 0.46% Cu (ADI Cu) and with 1.57% Cu and 1.51% Ni (ADI Cu+Ni) were studied after austenitisation at 900°C for 2h and austempering at 350°C. To achieve different microstructures the austempering times of 2 and 6h were used for ADI Cu, and 3 and 6h for ADI Cu+Ni. The microstructure was examined by "Leitz-Orthoplan" light microscope, while crack nucleation and growth, as well as final fracture mode have been examined by SEM JEOL JSM 6460LV, at 20kV. To study crack nucleation and growth "squeezing" samples were produced. The squeezing samples have a notch on one side and on the opposite side a squeezing (compressing) is performed. Thus, a tensile stress state could be induced at the notch side, favoring crack initiation.

The representative light micrographs of ADI microstructure are given in Fig.1. The graphite spheroidisation was more than 90%, with average graphite volume fraction of 10.5%, nodule size of 40 to 55 μm and nodule count of 50 to 80 per mm^2, Fig.1a. The microstructure of the ADI Cu after 2h and ADI Cu+Ni after 3 hours is fully ausferritic (Fig.1b), with acicular and plate-like appearance, respectively. After 6 hour of austempering treatment decreasing in retained austenite amount can be detected for ADI Cu, whereas for ADI Cu+Ni presence of bainite as a product of microstructure decomposition can be observed, Fig.1c. The process of crack nucleation and growth is shown in Fig.2 to 5, and it is similar for all tested ADI materials. Under initial stress the decohesion between graphite nodule and metal matrix can be noticed followed by the crack nucleation on free metal matrix surface, Fig.2. The cracks nucleation on free metal matrix surface in all cases were through ausferritic ferrite – retained austenite (F-A) interface, Fig.3. There is an atomic mismatch at the F-A interface, and the tensile stress that it can withstand is not as great as that of ausferritic ferrite or retained austenite [4]. After nucleation due to complex microstructure, where ausferrite sheaves are oriented randomly, the crack can continue to propagate along F-A interface, as well as perpendicular to or inclined by different angle on ausferritic shaves, Fig.2. Furthermore, the crack could branch and change direction. The initial cracks usually form on opposite sides of graphite nodule (Fig.4) and have a tendency to interconnect with other cracks formed on neighboring nodules, thus forming the main crack, Fig.5. The final step is linkage of main crack and favorable microcracks in order to form the final fracture. The different microstructures of tested ADI samples have a similar mechanism of crack nucleation and similar propagation path. However, the crack growth and fracture modes are different. In the case of fully ausferritic microstructure a ductile fracture occurs and crack growth is retarded by large plastic zone ahead crack tip. On the other hand, the presence of carbides at A-F interface after austempering for 6h decreases the toughness and favors appearance of quasi-cleavage or brittle fracture with conditions for fast crack growth [5].

Based on presented results, the following could be summarized. The crack nucleation and propagation path is similar for all tested ADI materials. From the decohesed graphite nodules-metal matrix surfaces, as first step of fracture, the cracks nucleate along the A-F interface into the metal matrix. The further crack propagation proceeds by internodular linkage of the initial microcracks. However, the final fracture mode and crack growth differ for different ADI materials and they are strongly influenced by corresponding ADI microstructure.

References

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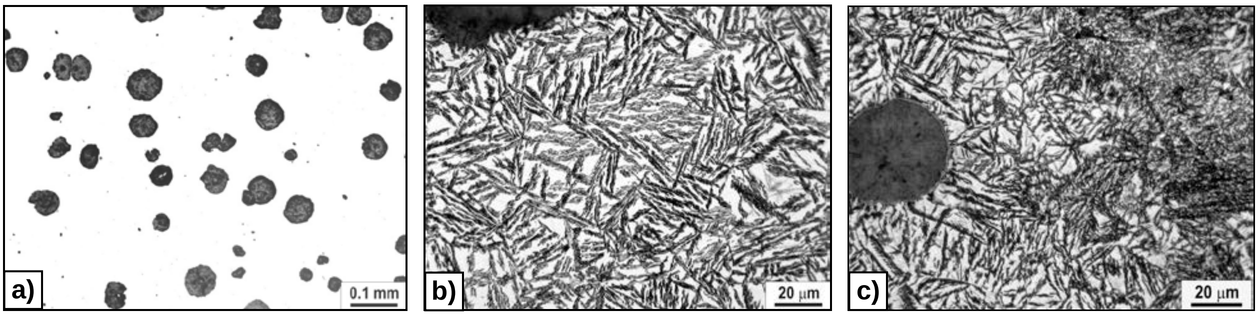

Figure 1. *Microstructure of austempered ductile iron alloyed with Cu and Ni: a) polished surface; b) austempered at 350°C for 3h, c) austempered at 350°C for 6h*

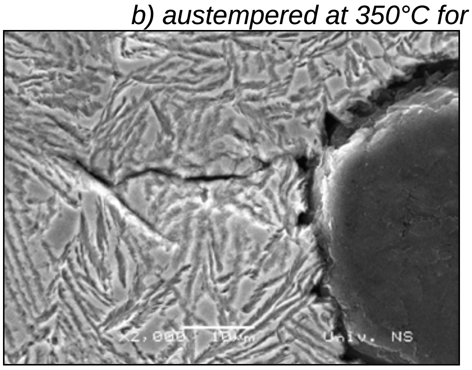

Figure 2. *Graphite-matrix decohesion and crack nucleation (ADI Cu+Ni 350°C/3h)*

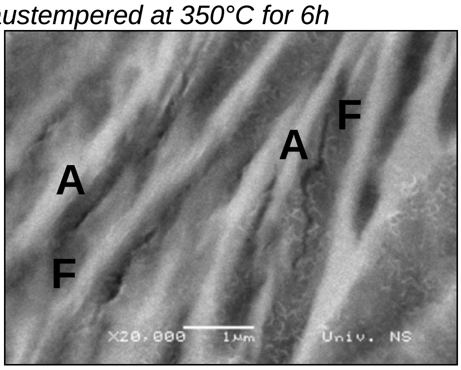

Figure 3. *Cracks along F-A interface (ADI Cu+Ni 350°C/3h)*

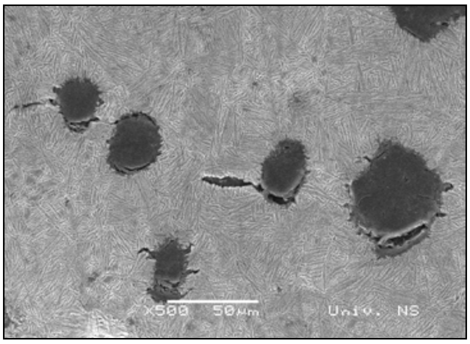

Figure 4. *Internodular linkage of microcracks (ADI Cu 350°C/2h)*

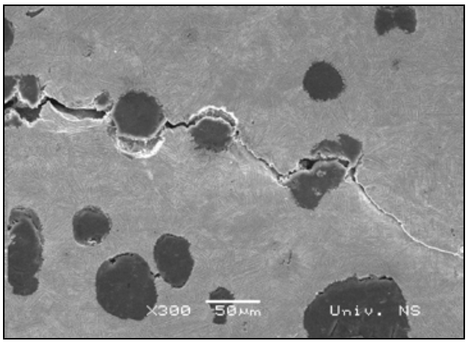

Figure 5. *Formation of the main crack (ADI Cu 350°C/6h)*