

Damage mechanisms and fracture toughness of dual-phase steels exhibiting a platelet-like microstructure

KARIM ISMAIL¹, LAURENCE BRASSART², ASTRID PERLADE³, PASCAL J. JACQUES¹, THOMAS PARDOEN¹

¹UCL, iMMC, Louvain-la-Neuve, Belgium

²Monash University, Melbourne, Australia

³ArcelorMittal, Maizières-lès-Metz, France

Dual-phase steels have long been used in the automotive industry for their excellent mechanical properties in terms of strength and ductility balance combined to a low processing cost. The good compromise between strength and ductility results from the very different properties of the constituent phases, namely ductile ferrite and hard martensite.

In contrast with the plastic flow properties, the fracture toughness of dual-phase steels (quantified by K_{Ic} or J_{Ic}) has been far less investigated. Common values of the fracture toughness are around 100 kJ.m^{-2} or lower. However, a minimum level of fracture toughness is required to prevent the propagation during forming operations of small edge damage or cracked zones induced by cutting. Therefore, unravelling the relationship between fracture toughness, microstructure and damage mechanisms is essential to develop advanced steels with superior forming ability. Furthermore, reaching superior fracture toughness could open to other potential applications.

Dual-phase steels are usually processed following an intercritical annealing which generally leads to equiaxed martensite particles. An alternative heat treatment, consisting of a double annealing as first proposed N.J. Kim and G. Thomas [1], brings about martensite particles in the form of platelets. A recent study on bulk samples of such steels shows that this microstructure can potentially lead to a very high fracture toughness, while retaining good properties in terms of strength and ductility [2].

In this work, rather oriented towards thin sheets, the Essential Work of Fracture (EWF) method [3] is used to quantify the work per unit area spent in the fracture process zone by separating it from the total work expended for material failure. EWF values in excess of 300 kJ.m^{-2} have been found on platelet-like microstructure steels confirming their interesting resistance to the propagation of a crack. Equiaxed microstructures are investigated as well and the impact of martensite volume fraction is assessed. Moreover the work of necking is separated from the work of damage using an extension of the EWF method [4].

As a first step towards the general objective of investigating the fundamental damage mechanisms governing the fracture toughness of dual-phase steels, a model for the plastic behaviour and for the damage mechanisms related to the microstructure has been developed. A finite element based unit cell approach is used to address the plastic behaviour with a particular focus on the effect of morphology and orientation, as well as of martensite volume fraction and of carbon content.

The data extracted from the elastoplastic analysis are fed into a cellular automaton approach of the damage evolution [5] with the aim of taking into account the effect of microstructural heterogeneities on fracture strain. Being able to incorporate a large number of different particles distributed differently in the microstructure in addition to a distribution of critical stress for nucleation, this model introduces a statistical description of the material while using relatively simple damage evolution laws.

References

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