

Damage Mechanisms and Fracture Toughness of Fibrous Dual-Phase Steels for Automotive Applications

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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 $100[\text{kJ.m}^{-2}]$ 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 inclusions. An alternative heat treatment, consisting of a double annealing as first proposed N.J. Kim and G. Thomas [1], brings about fibrous martensite inclusions. A very recent study on such steels shows that this fibrous microstructure can potentially lead to a very high fracture toughness, while retaining good properties in terms of strength and ductility [2].

The general objective of this research is to investigate the fundamental damage mechanisms governing the fracture toughness of Dual-Phase steels. Our approach is based on the processing of microstructures in which parameters are varied one by one. In particular, both equiaxed and fibrous microstructures are investigated in the form of thin sheets. Experimental works as well as computational modelling are used to study the behaviour of such steels.

Experimentally, a serial sectioning procedure reveals that the so-called fibrous martensite turns out being platelets. Moreover, the Essential Work of Fracture (EWF) method [3] is used to quantify the work per unit area spent in the fracture process zone for material failure by separating it from the total work expended for material failure. The work of necking is separated from the work of damage using an extension of the EWF method [4].

A model for the plastic behaviour and for the damage mechanisms related to the microstructure has been developed as a first step towards the modelling of the fracture toughness. A finite element based unit cell approach is used to address the plastic behaviour with a particular focus on the effect of morphology, 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]. This model introduces a statistical description of the material while using relatively simple damage evolution laws.

References

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