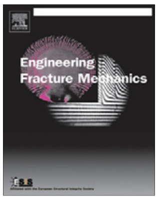
Engineering Fracture Mechanics 78 (2011) 469–486

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

journal homepage: www.elsevier.com/locate/engfracmech



Modelling of damage and failure in multiphase high strength DP and TRIP steels

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ARTICLE INFO

Article history:
Received 19 June 2009
Received in revised form 31 May 2010
Accepted 19 August 2010
Available online 24 August 2010

Keywords:
Multiphase steels
Microstructure
Representative volume element
GTN model
Cohesive model

ABSTRACT

Multiphase high strength steels such as dual phase (DP) and Transformation Induced Plasticity (TRIP) steels show excellent strength and formability due to the coexistence of harder and softer phases in their microstructures. The damage mechanism and failure behaviour of these steels are very complex and strongly affected by microstructural constituents. In experiments, two failure modes-cleavage and dimple fracturing-were observed simultaneously at the microscale. The void nucleation was caused by the de-bonding of martensite from ferritic matrix or martensite cracking. The crack initiation and the contribution of each fracture mode depended on the stress state or triaxiality, the purity degree, the volume fraction of retained austenite, the carbon content of retained austenite and martensite, and the locations of the neighbouring austenite grain and martensitic islands. To describe the effects of the multiphase microstructure, representative volume elements (RVE) were used within the framework of continuum mechanics. The partitioning of carbon in microstructure was taken into account for the flow curve description of each individual phase. The Gurson–Tvergaard–Needleman (GTN) damage model was applied to the RVE simulations to describe the ductile damage occurring mostly in the softer ferritic phase. Additionally, a cohesive zone model (CZM) was used to represent a cracking mechanism as the de-bonding of interfaces. The failure prediction was verified with different sheet forming experiments. The effects of amount and strength of martensite in a DP microstructure were also numerically investigated.

1. Introduction

Modern high strength steels have been developed for the automotive industry for the purpose of reduction of car body weight, improved passive safety features, and energy saving considerations. They are of special interest due to their simultaneous high strength and good formability. These types of steels, for instance, DP, TRIP, CP (complex) or partly martensitic steels, contain different phases in their microstructure [1–3]. The application of multiphase steels in the automobile industry is illustrated in Fig. 1 provided by the European program Ultra Light Steel Auto Body Advanced Vehicle Technology (ULSAB-AVC) [4]. In the Figure, the proportion of each steel grade used in a car body structure, and its yield and tensile strength are outlined. However, in some cases, the application of multiphase steels is restricted because of their complex fracture behaviour. A reason for these characteristics can be given by the presence of different microstructural constituents and their interaction. To ensure the reliable utilization of the multiphase steels, influences of the microstructure on their formability and failure behaviour must be clearly understood.

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doi:10.1016/j.engfracmech.2010.08.017

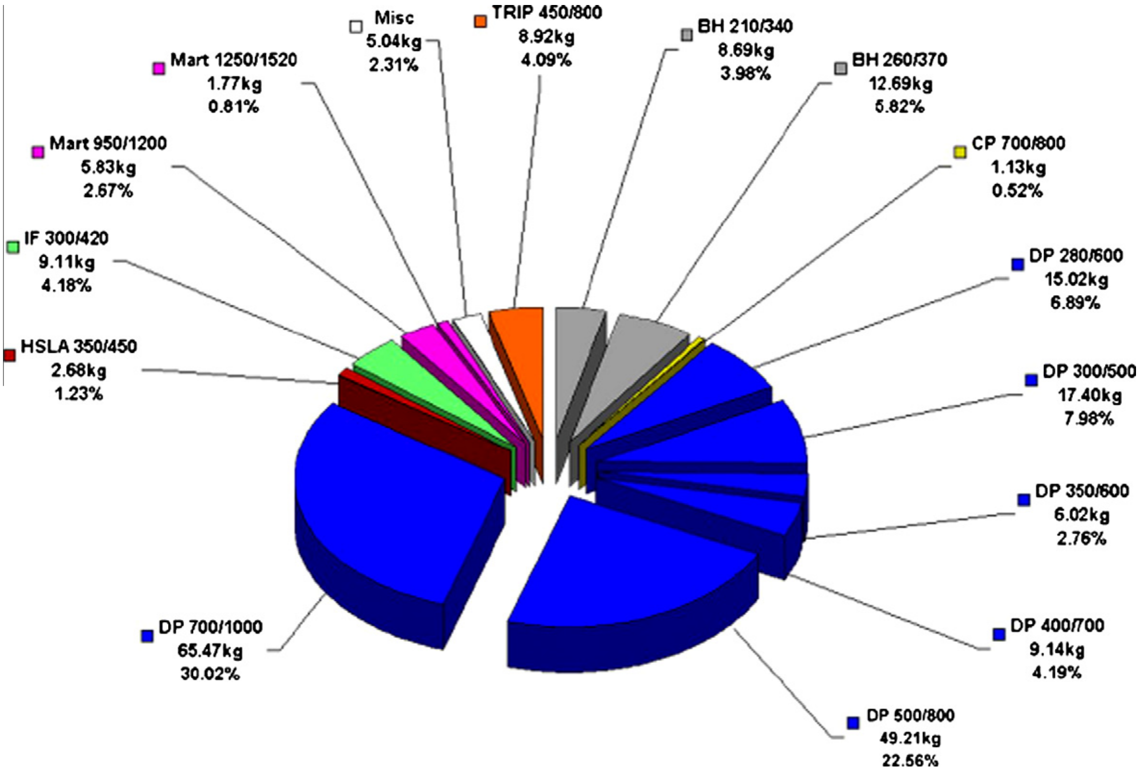

Fig. 1. Steel grade distribution in PNGV-Class body structure [4].

In recent years, computational modelling has been successfully established to study material behaviour at the microstructure level. An axisymmetric unit cell model based on a regular array of second phase particles arranged on a BCC lattice was used to investigate deformation mechanisms of ferrite–pearlite structural steels [5]. The tensile behaviour of these steels could be accurately estimated even with a relatively large volume fraction of the pearlite phase. In [6], numerical simulations of crack initiation and growth in real microstructures of tool steels were done. By virtual testing of artificially designed materials it is possible to compare fracture resistances of different microstructures and to recommend optimised microstructure features. A micromechanical model based on the Veronoi algorithm was used by Nygards et al. [7] to evaluate the mechanical behaviour of two-phase ferritic/pearlitic steels. Periodic grain structures and periodic representative cells were generated with the desired volume fraction of pearlite. Schmauder et al. [8] applied a physical-based micromechanical approach in order to study the influence of residual stresses on local and global properties of metal matrix composites. It was found that random artificial arrangements of particles are less prone to damage in the matrix phase as compared to particle clustering, which is often found in real microstructures. Ductile failure of dual phase steel was predicted when plastic strain localisation occurred, which resulted from the inhomogeneous deformation concerning different hardnesses of the martensite phase and ferrite matrix [9]. The FE analyses were based on actual steel microstructures. Microstructure-level inhomogeneities serve as the initial imperfections triggering the plastic instability during the deformation process. A similar procedure was applied for predicting ductility and failure modes of TRIP steel under various loading conditions [10]. Micromechanical modelling of cells was coupled with the Gurson–Tvergaard damage model to capture the deformation and fracture behaviour of DP steels by Al-Abbasi et al. [11]. The parameters in the damage model were determined and calibrated considering void volume fraction, stress triaxiality and the mechanics of failure in DP steels. Han et al. [12] analysed the TRIP effect that accompanies the mechanically-induced martensitic transformation in TRIP-aided multiphase steel. The probability of nucleation occurring at a given site could be calculated for each martensitic variant as a function of the mechanical interaction energy between the externally applied stress state and the lattice deformation in austenite during phase transformation based on the Kurdjumov–Sachs (K–S) orientation relationship. Uniaxial tensile tests were simulated using a model that takes void nucleation and growth into account. In such manner, the optimum volume fraction and transformation stability of the retained austenite in TRIP-aided steel could be determined.

The aim of this work is to predict damage and failure in multiphase steels (DP and TRIP steels) during forming processes. These kinds of steel consist of a ferritic matrix with dispersed second phases like bainite, martensite and retained austenite in different amounts and morphologies depending on their processing path. A microstructure-based approach by means of representative volume elements (RVE) was used. The microstructural characteristics such as phase fraction, phase distribution, morphology, and different fracture mechanisms of each individual phase could be considered. Constitutive models taking into account carbon partitioning during intercritical annealing, chemical composition, and dislocation theory were used