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Procedia Engineering 197 (2017) 60 – 68

Procedia Engineering

www.elsevier.com/locate/procedia

DYMAT 23rd Technical Meeting

Dynamic Fracture of Ductile Materials

Coupled ASB-and-microvoiding-assisted dynamic ductile failure

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Abstract

Adiabatic shear banding (ASB) is a dynamic localization phenomenon resulting from thermomechanical instability under high strain rate and low stress triaxiality loading conditions. High strength, steels and lightweight alloys of titanium and aluminum are highly susceptible to this phenomenon which leads to premature material failure. At an advanced stage of the localization process, the adiabatic shear bands have been shown to contain micro-voids which coalesce to form cracks and ultimately lead to the fracture of the structure. A physics-motivated, unified constitutive model accounting for the coupled effects of ASB and micro-voiding has been developed in the context of large deformation, high strain rate and high temperature rise. The enlarged model is herein implemented as user material into the engineering finite element (FE) computation code LS-DYNA in the context of standard FE kinematic formulation and its performances are assessed.

Peer-review under responsibility of the scientific committee of the International Conference on Dynamic Fracture of Ductile Materials

Keywords: adiabatic shear banding, ductile damage, viscoplasticity, high strain rate loading

1. Introduction

Structures are often subjected to severe loading and one of the mechanisms which may be responsible for premature material degradation during impact loading is adiabatic shear banding (ASB). High strength alloys of titanium (e.g. Ti-6Al-4V, see Meyers et al. (2001) [1]) and aluminum (e.g. AA7075, see Mondal et al. (2011) [2])

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Peer-review under responsibility of the scientific committee of the International Conference on Dynamic Fracture of Ductile Materials
doi:10.1016/j.proeng.2017.08.082

which are predominantly used as constitutive materials of aeronautical structures are susceptible to this phenomenon. The adiabatic shear bands are narrow zones of localized shear deformation resulting from thermomechanical instability. When the thermal and/or microstructural changes induced softening dominates the strain/strain rate hardening, the material state indeed becomes unstable leading to ASB, see Zener and Hollomon (1944) [3]. ASB is accordingly a cause of premature failure, and to ensure the integrity of structures, it is therefore important to numerically model its consequences at the structure scale.

Longère and Dragon (2015) [4] carried out experiments on shear compression specimens (SCS) (see Fig. 1a) dimensioned to allow for generating a local shear loading under a global compression loading. The observation of the fractured surface of the SCS (see Fig.1 b-d) showed dimples as the result of micro-voiding in the wake of the ASB. It is clearly seen that the fracture occurred due to two successive mechanisms: adiabatic shear banding and then micro-voiding.

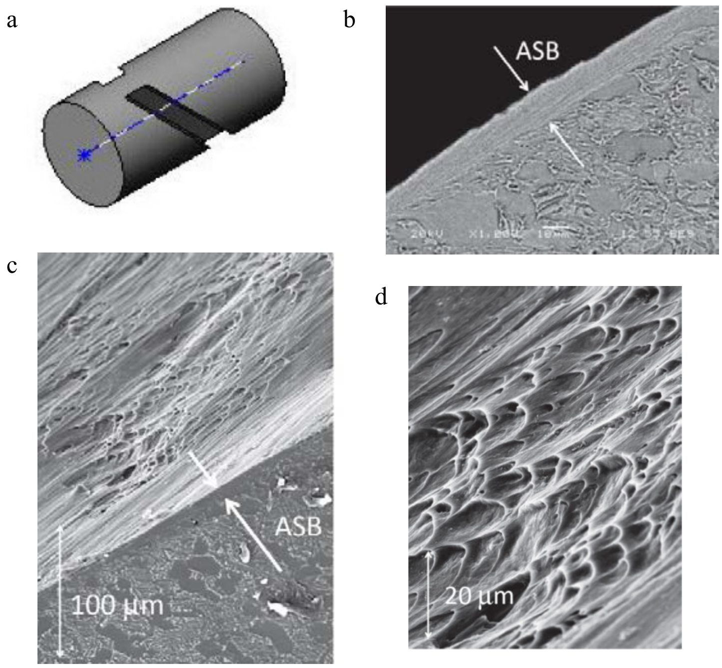

Fig. 1. After[4] (a) Shear compression specimen; Microscopic observation of fractured surface (b) 2D view; (c) 3D view; (d) Detailed 3D view

A physics-motivated constitutive model describing the ASB induced material degradation was developed by Longère et al (2003) [5] in the context of a large scale postulate where the size of the representative volume element (RVE) exceeds the shear band width and thus making it practical for numerical implementation involving large structures. The effects of ASB initiation and evolution on the RVE (material point) response are double: kinematic, degrading, namely (i) a progressive deviation of the plastic flow for the RVE (including possibly a cluster of bands and surrounding material) connected to (ii) a progressive anisotropic degradation of the elastic and plastic moduli. The performances of the ASB-model have been assessed considering the dynamic shearing of a hat-shaped structure, see Longère et al (2005) [6] then a ballistic problem, see Longère et al (2009) [7].

The aforementioned ASB-model has been enriched in order to reproduce the consequences of micro-voiding (MV) in the band wake, see Longère and Dragon (2016) [8]. The enlarged (ASB+MV)-model is herein implemented as user material into the engineering finite element (FE) computation code LS-DYNA in the context of standard FE kinematic formulation. The objective here is to conduct a parametric study on a representative volume element.

The motivations for employing the advanced model developed by Longère et al. (2003, 2016) [5,8] are briefly outlined in Section 2. Section 3 gives the main equations governing the constitutive model with coupled effects of