From shear banding to folding: instabilities in ductile materials

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When a ductile material is subject to severe strain, failure is preluded by the emergence of shear bands, which initially nucleate in a small area, but quickly extend rectilinearly and accumulate damage, until they degenerate into fractures. Therefore, research on shear bands yields a fundamental understanding of the intimate rules of failure, so that it may be important in the design of new materials with superior mechanical performances.

Modelling of a shear band as a slip plane embedded in a highly prestressed material and perturbed by a mode II incremental strain, reveals that a highly inhomogeneous and strongly focussed stress state is created in the proximity of the shear band and aligned parallel to it. This evidence, together with the fact that the incremental energy release rate blows up when the stress state approaches the condition for ellipticity loss, may explain the rectilinear growth of shear bands and the reason why they are a preferred mode of failure for ductile materials [1,2].

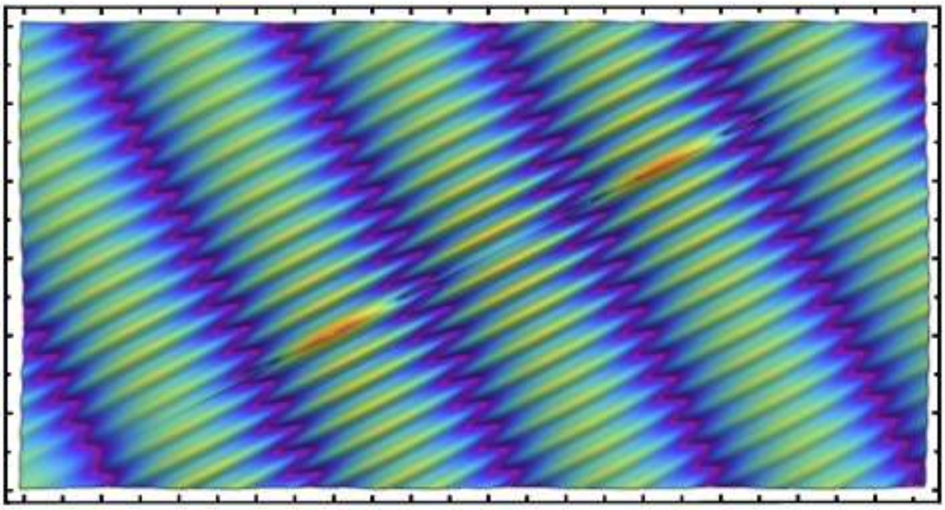

Fig. 1- Interaction of waves with two shear bands aligned on the same line

A shear band of finite length, formed inside a ductile material at a certain stage of a continued homogeneous strain, provides a dynamic perturbation to an incident wave field, which strongly influences the dynamics of the material and affects its path to failure. The investigation of this perturbation is presented for a ductile metal, with reference to the incremental mechanics of a material obeying the J2–deformation theory of plasticity (a special form of prestressed, elastic, anisotropic, and incompressible solid). It is shown that the presence of the shear band induces a resonance, visible in the incremental displacement field and in the stress intensity factor at the shear band tips, which promotes shear band growth. Moreover, the waves scattered by the shear band are shown to generate a fine texture of vibrations, parallel to the shear band line and propagating at a long distance from it, but leaving a sort of conical shadow zone, which emanates from the tips of the shear band, Fig. 1, [3].

The same mathematical tools developed for the analysis of shear bands in ductile materials will be shown to lead to folding and faulting in constrained Cosserat materials, when these have a strong anisotropy, so that they are close to the elliptic boundary. In fact, folding is a process in which bending is localized at sharp edges separated by almost undeformed elements and folding in these materials can originate from ellipticity loss, Fig. 2, [4-6].

Fig. 2 - Chevron folds in layered rocks near Millook Haven (UK) modeled as a constrained Cosserat material.

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