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Kink band propagation in layered structures

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Abstract

Confined layered structures in layer-parallel compression exhibit kink band deformation that has an associated severe initial instability. However, once the first kink band forms the system restabilizes and the bands then propagate in two mechanisms: band broadening and band progression. Previous work on triggering the initial instability and band broadening is now extended to include band progression. A new model for this propagation mechanism that successfully accounts for the modulating restabilizing response is presented and quantitative comparisons with the physical experiments yield excellent results.
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1. Introduction

Kink banding is a phenomenon observed on a variety of scales across the physical sciences. It should be considered as a potential failure mode for any layered or fibrous material, held together by external pressure or some form of internal "glue", and subjected to layer-parallel compression. Examples can be found in the deformation of geological strata (Anderson, 1964; Hobbs et al., 1976; Price and

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Cosgrove, 1990), wood and fibre composites (Kyriakides et al., 1995; Reid and Peng, 1997; Fleck, 1997; Hull and Clyne, 1996; Byskov et al., 2002; Vogler and Kyriakides, 2001), and internally in wire and fibre ropes (Hobbs et al., 2000). There have been many attempts to reproduce kink banding theoretically, from early mechanical models (Rosen, 1965; Argon, 1972), to more sophisticated formulations coming from both continuum mechanics (Budiansky, 1983) and numerical perspectives (Vogler et al., 2001).

In a recent paper (Wadee et al., 2004) the issue of kink band deformation, focused directly on the geological application of the folding of rock strata under tectonic action with large overburden pressures, was examined both experimentally and theoretically. This led to a model based on energy principles which exhibited the key features encountered in the physical experiments: a severe instability initiating the kink band followed by increasing deformation manifesting itself in band broadening with subsequent restabilization. A key development was the inclusion of transverse layer compressibility that allowed the calculation of the initial kink band orientation angle, which in the past has been an elusive quantity to predict theoretically. Other important inclusions were those of bending and "foundation" terms in the energy formulation that could be measured quantitatively in simple physical experiments in a straightforward manner. Comparisons with these experiments showed an encouraging trend with the shortcoming that only one band was formed during the loading history.

As it is extremely unlikely in geological situations that kink bands are found in isolation, the original model is extended to allow the possibility of more folds of this type occurring. In the laboratory it can be seen that as the first band locks up, i.e. when the rotation and the band width cease to grow, the next kink appears from the contact of the band with the undeformed boundary layers (see Fig. 1); a fingerprint of this is seen as a new snap instability on the load–deflection plot. This second band subsequently restabilizes as it reaches its maximum rotation and width, which causes a third band to appear and propagate and so on.

The model presented in the present paper uses the principles of Wadee et al. (2004) to include the band progression propagation mechanism. A uniform layer thickness criterion is defined to halt the broadening of the current kink band and to initiate a new one. Using the properties of the current band, the properties of the new band are inferred under the condition of continuity of deformation; as the current band is assumed to stop rotating and broadening its influence from the equilibrium equation is eliminated as its terms in the potential energy become constants. Therefore, the equilibrium equations take on a modular form with separate bands effectively having separate potential energy functions and equilibrium equations.

The current paper is set out as follows: first the model developed in Wadee et al. (2004) is extended to cover the appearance of multiple kink bands; this is followed by a detailed discussion of the quantitative comparisons between experiment and theory with a method for estimating when new bands may initiate. Conclusions are then drawn.

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