A Workability Criterion for the Transformed Adiabatic Shear Band Phenomena during Cold Heading of 1038 Steel

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A criterion for predicting the workability limits for internal brittle failure was developed for cold heading of 1038 steel. The criterion considers internal defects caused by microstructural changes generated by adiabatic shear. This transformation is termed the transformed adiabatic shear band (TASB) phenomena. The defect that develops is the formation of brittle martensite as a result of the temperature rise and fall inside the adiabatic shear band (ASB). In this work, the material is considered to have a TASB defect when the temperature inside the ASB exceeds the phase transformation temperature ($A_c3$). The empirical formulas provided by Andrews[1] were used to determine transformation temperatures. Microhardness testing and etching with 2% Nital and Le Pera etchants were performed on the sectioned specimens to locate and study the TASB. In order to simulate the cold heading process, a drop weight compression test was used and modeled with finite-element analysis (implemented within ABAQUS/Explicit).

Keywords: adiabatic shear band, cold heading, cracks, transformed band, workability

Introduction

The occurrence of any failure is a major limitation governing the limits of workability in any forming process. Therefore, the prediction of failure occurrence and knowledge of the workability limits in metal forming operations have attracted the attention of many researchers for more than five decades. Workability refers to the relative ease with which a material can be shaped through plastic deformation. Thus, workability is a function of the material and the forming process.

The cold heading process (CHP) is currently one of the most important metal forming operations because of its many advantages over machining. These advantages include high productivity, complex final shapes, and minimum wastage of material. The CHP, which is a multistage forming process performed without an external heat source, involves applying a force to the free end of a metal workpiece. The CHP is used to produce a large variety of components such as fasteners, studs, small shafts, and other machine parts.

At present, the cold heading industry is tending toward faster headers, reduction in the number of manufacturing stages, and production of high-strength fasteners without final heat treatment. To achieve these goals, modified process designs are required, resulting in higher strains and strain rates, which cause two familiar types of defects in the cold headed workpiece. The first is the external oblique or longitudinal crack due to exhaustion of the material ductility, and the second is the internal crack caused by the adiabatic shear band (ASB) phenomenon, which sometimes results in splitting of the fasteners heads,[2] as shown in Fig. 1. Specifically, an ASB is a narrow, nearly planar or two-dimensional

![Fig. 1 An internal crack along the adiabatic shear band in a cold headed fastener](image_url)

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A Workability Criterion for the Transformed Adiabatic Shear Band Phenomena (continued)

region of very large shearing that sometimes occurs in metals and alloys as they experience intense dynamic loading (as in the CHP). Once the band is fully formed, the two sides of the region are displaced relative to each other, although the material still retains full physical continuity from one side to the other. The thickness of the most heavily sheared region may reach a few tens of microns, and its length might extend many millimeters or even centimeters. Commonly, the formation of ASBs occurs by impact loading at high strain rates (higher than $10^2 \text{ s}^{-1}$) and high strains. With increasing plastic deformation, the occurrence of strain hardening and strain rate hardening results in an increase in the flow stress for most materials. Additionally, much of the energy for plastic work (90-95%) is converted into heat, causing a local temperature increase and a flow stress decrease. Thus, a competing mechanism between the work hardening and the thermal softening commences and continues in the deformation zone. As the work hardening mechanism dominates over the thermal softening at the beginning, an increase in the flow stress occurs; but with continuing deformation, the thermal softening mechanism can progressively dominate over strain hardening increases, which then triggers unstable deformation. This instability condition will force the deformation to localize into a narrower band that, through further localization, can lead to final failure.

There are two types of ASBs: namely, deformed adiabatic shear bands (DASBs) and transformed adiabatic shear bands (TASBs). Deformed adiabatic shear bands occur in materials that do not undergo phase transformation, or when the local increased temperature in the band does not reach the phase transformation temperature. The damage and fracture process in DASBs involves a number of metallurgical events involving different steps between void nucleation and crack propagation. Transformed adiabatic shear bands occur in materials that undergo phase transformations, and are often found in high-strength steel in locations

where the critical temperature for the transformation of ferrite to austenite ($A_{C3}$) is surpassed. The TASBs are characterized by their bright contrast after etching by 2% Nital and are often referred to as "white bands." The white character is due to the formation of martensite during the rapid cool to room temperature.

Transformed adiabatic shear bands fracture in a brittle way in directions normal to the local tensile stress. In dynamic events a tensile wave may impact an existing transformed band from any direction depending on the geometry. If the matrix is sufficiently ductile, brittle fracture will be limited to the band, but sometimes the fracture may extend to the matrix in a brittle manner. Even if the band did not fracture, it remains as a brittle fracture path in the middle of the ductile matrix and it might lead to catastrophic failure.

The shape and the type of ASB depends on the material properties. Cepus et al. concluded that the higher the strength of the steel, the easier it is to form a narrow ASB and the faster the band would localize. It is more likely to find TASBs in high-strength materials when deforming at high strain rates and large strains. For the same strain rates and strains, the lower strength, more ductile steel will typically have a DASB that contains voids and cracks. Low-strength materials need much higher strains