

Mechanics of large strain extrusion machining and application to deformation processing of magnesium alloys

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Abstract

An analysis of the mechanics of large strain extrusion machining (LSEM), a constrained chip formation process, is presented for deformation processing of bulk alloys. The deformation field is shown to be narrowly confined and controllable, with attributes ranging from conventional deformation processing to severe plastic deformation. Controllable deformation parameters include strain/strain rate, hydrostatic pressure, temperature and deformation path. These attributes are highlighted in deformation processing of Mg AZ31B, an alloy of commercial significance but noted for its poor workability, into sheet and foil forms. Noteworthy features of the processing are suppression of segmentation, realization of a range of strains and deformation rates, engineering of microstructures ranging from conventional to ultrafine grained, and creation of sheet/foil from the bulk in a single step of deformation without pre-heating. Guidelines for realizing specific sheet attributes, and scalability of LSEM for production are analyzed and discussed.

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1. Introduction

Production of magnesium alloy sheet and foil is one of the principal technological challenges for weight reduction in the discrete products manufacturing sector. Although magnesium is abundant in mineral form and can be refined and cast relatively inexpensively [1,2], creation of final product forms such as sheet and strip is quite expensive due to the poor formability of this hexagonal close-packed (hcp) metal [1–4]. Enhancing workability by promoting basal slip or activation of non-basal slip typically requires heating above 200 °C [5]. Even at this temperature, multi-

ple deformation steps are needed not only to accumulate strain in the material and refine microstructure, but also to reduce the thickness of the sheet [3,4,6]. Sheet is traditionally produced from Mg ingot by either rolling or extruding into final shape [3,4,6]. Alternatively, the material may be cast directly into sheet forms using twin-roll casting (TRC) [7,8].

The need for enabling technologies to produce Mg sheet has spawned studies of various deformation processes. In the rolling (extrusion) of Mg ingot, the workpiece and rolls are generally pre-heated to the high temperatures (~200 °C) needed to activate slip. Typically, 15–30% thickness reduction per pass is imposed in 3–7 passes, with intermediate annealing between passes (2–3 heats). Processing speeds are kept small (~30 m min⁻¹) to avoid cracking [3,4,9]. Consequently, production costs are high in comparison to those of conventional alloy sheet, e.g. aluminum

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and steel. The multiple annealing and pre-heating stages also adversely impact energy costs. In TRC, roll speeds are again kept small in order to achieve uniform solidification and a crack-free sheet [8]. The cast sheet is then further processed by conventional rolling or differential speed rolling (DSR) [10,11] in order to homogenize and refine the cast microstructure and reduce the thickness to ~ 2 mm, which is also the typical minimum thickness achieved to date by TRC. An unavoidable consequence of the high temperature steps and material inhomogeneity is large material loss [9].

Together with DSR, conventional severe plastic deformation (SPD) techniques such as equal channel angular pressing (ECAP) [12–14] and high-pressure torsion [15] have been proposed to break up the initial cast microstructure and texture by intense shear deformation. Compared to conventional rolling, these techniques produce finer microstructures, generally 1–3 μm grain size, and less intensive (0002) textures, which are essential for subsequent sheet forming or superplastic forming [16,17]. However, the techniques in themselves cannot be used to make sheet directly from ingot or billet, as they do not provide for large shape changes or continuous production. Elevated temperature deformation (~ 200 – 250 °C) through workpiece and tool pre-heating is again essential to enable the deformation processing.

There have been attempts via rolling to use the heat generated in situ by the deformation and minimize workpiece pre-heating, maximize percentage reduction per pass and increase productivity. The principal approach has involved

the use of higher roll speeds, from ~ 250 to 1000 m min^{-1} . While this is potentially viable [18], the large deformation zones typical of rolling (or extrusion) and the heat lost into the correspondingly large tools preclude the efficient conversion of plastic work into a local temperature rise [6].

The present study describes a deformation process for making sheet/strip/foil – large strain extrusion machining (LSEM) [19,20] – that imposes intense, confined deformation enabling efficient conversion of the plastic work into a temperature rise in the deformation zone. It is shown, based on the mechanics of LSEM, which can be confined and controlled by the choice of geometrical and kinematic process parameters, strain, temperature and hydrostatic pressure, thereby minimizing or eliminating the need for pre-heating in processing of alloys of poor workability (e.g. cast alloys, hcp systems). Continuous production of MgAZ31B alloy sheet and foil (referred to henceforth as sheet) from bulk forms, in a single step of deformation, using large deformation rates and high hydrostatic pressure, is demonstrated. Concomitantly, the intense, confined shear deformation underlying this process may be used to create ultrafine-grained (UFG) forms comparable to current DSR and other SPD techniques. Examples of UFG Mg alloy sheet created by LSEM are discussed.

2. Mechanics of LSEM

Fig. 1 shows a schematic of the plane strain LSEM used in the present study. A sharp, wedge-shaped tool removes a preset depth (undeformed chip thickness, t_o) and width (t_w)

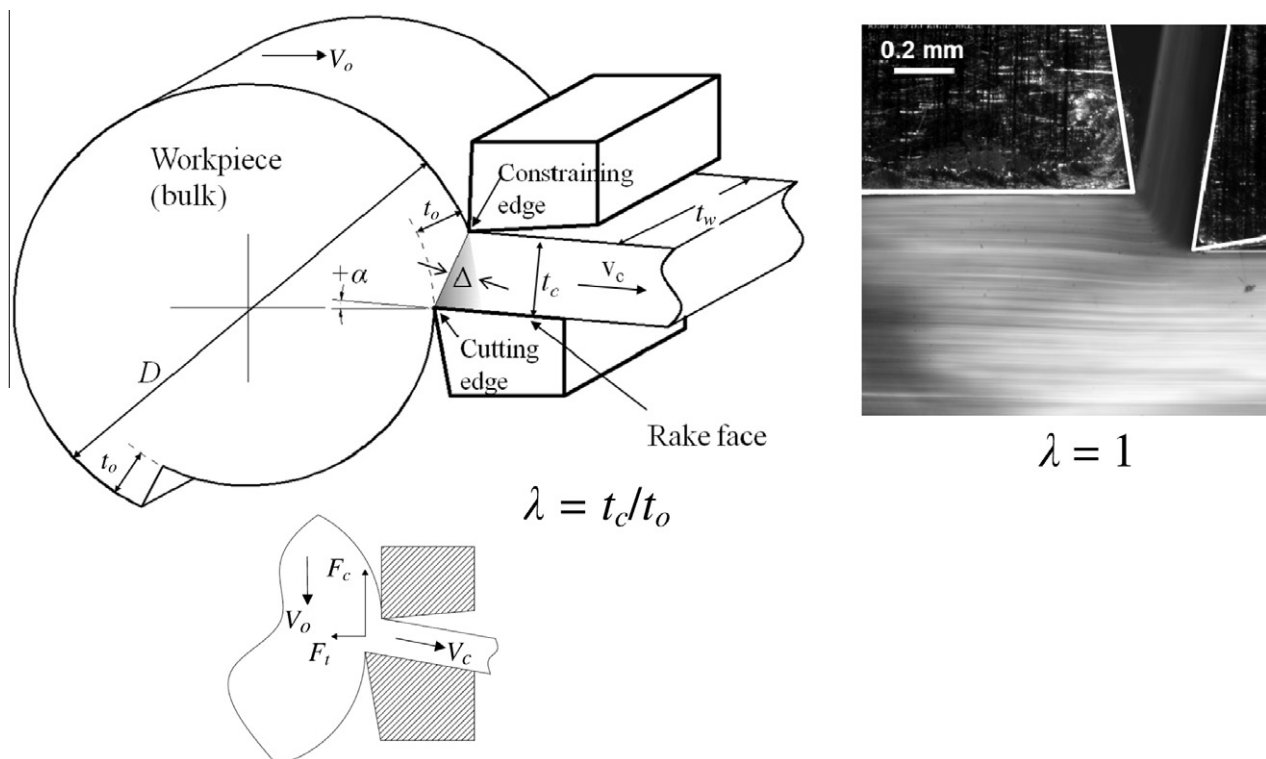


Fig. 1. Plane-strain LSEM showing parameters, and forces, F_c (cutting), and, F_t (thrust), on the workpiece. Inset is an image of the process obtained by averaging 200 consecutive frames from a high-speed image sequence ($\lambda = 1$). See also [Supplementary high-speed video](#).

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