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Material testing of copper by extrusion-cutting

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Abstract

An investigation was carried out on the use of extrusion-cutting as a material test method operating at severe conditions of strain, strain-rate and temperature, such as in machining. In extrusion-cutting, a shoe constrains the chip back surface producing a geometrically defined orthogonal cutting process which can be modelled using methods from the theory of plasticity such as, e.g., slip-line and upper-bound. The process was previously proposed for use as a material testing technique to determine the shear flow stress of materials under strains, strain rates and temperatures relevant for analytical modelling of metal cutting. This work represents a new step where the final objective is the generation of stress-strain curves that can be used in analytical models as well as using Finite Element Method (FEM) simulations. A new experimental setup for extrusion-cutting using discs as workpieces was developed and implemented on a CNC lathe. An investigation was carried out extrusion-cutting copper discs using high-speed-steel cutting tools at 100 m/min cutting speed. Flow stress values for copper under machining-relevant conditions were obtained from measurement of the extrusion-cutting force on the tool and application of a simple upper-bound model for the extrusion-cutting process. An attempt to extend the validity of test data to cover a range of cutting conditions was made, and suggestions for improvement of the simple theoretical model given.

Keywords: Metal cutting; Experimental investigation; Pure copper; Material testing; Extrusion-cutting

Nomenclature

c specific heat
d width of deformation zone
F_c cutting force
F_t thrust force
h tool-shoe offset
J mechanical equivalent of heat
k shear flow stress
L contact length
m= $\cos 2\psi$ friction factor
p=F_c/wt extrusion pressure
S tool-shoe gap
t undeformed chip thickness
t′ chip thickness
T temperature in the deformation zone
v cutting speed
w width of cut
$\dot{W}$ cutting power
Z length of shear plane
α (alpha) rake angle
γ (gamma) shear strain
$\dot{\gamma}$ (gamma dot) shear strain rate
ΔT (Delta T) adiabatic temperature increase
ε (epsilon) equivalent strain
$\dot{\varepsilon}$ (epsilon dot) equivalent strain rate

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θ (Theta) fan angle
$\lambda = t'/t$ (lambda) chip compression factor
$\Lambda = S/h$ (Lambda) imposed chip compression factor
ρ (rho) density
σ (sigma) flow stress
τ (tau) shear stress
Ψ (psi) friction angle

1. Introduction

Material testing for use with modelling of machining is particularly tricky and so far no one has been able to develop a technique for determining the flow stress of materials under conditions prevailing in metal cutting, i.e., at high strains, strain rates and temperatures [1]. In literature one can find several approaches for obtaining material data at high strain rates and temperatures, e.g., a Split Hopkinson Pressure Bar (SHPB) complemented with an inductive heat source [2], but they usually cover equivalent strains between 0 and 0.3-0.4 while, during cutting, strains reach values up to 5 [1]. Values beyond test results are then usually extrapolated. A first attempt of using metal-cutting test as a high strain rate material property test at strains larger than those normally achievable in conventional tests was developed by Lira and Thomsen [3] but the approach suffers from the fact that ordinary cutting is characterized by an unrestricted geometry which is difficult to model analytically. This approach was more recently adopted in [4], [5] and [6], and applied to determine work flow stress and friction at tool-chip interface from experimental data for cutting and thrust forces and chip thickness, based on application of Oxley's slip-line field in reverse [7].

In this study we apply the method based on extrusion-cutting previously proposed in [8] and shown in Fig. 1 where a shoe constrains the chip back surface producing a geometrically defined cutting process which can be modelled using methods from the theory of plasticity such as, e.g., slip-line and upper-bound, Fig. 2. The process was proposed for use as a material testing technique to determine the shear flow stress of materials under strains, strain rates and temperatures relevant for cutting. In [8], equations (1) - (4) were used to calculate a representative set of values for flow stress, strain, strain rate and temperature, respectively, directly from force measurement and assuming a geometry determined by the tool-shoe position. See specific definitions for the used terms in the Nomenclature.

This work represents a new step where the final objective is the generation of stress-strain curves that can be used in analytical models as well as using Finite Element Method (FEM) simulations. A new experimental setup for extrusion-cutting using discs as workpieces was developed and implemented on a CNC lathe, after which an experimental campaign was carried out to produce material data for pure copper using the extrusion-cutting method.

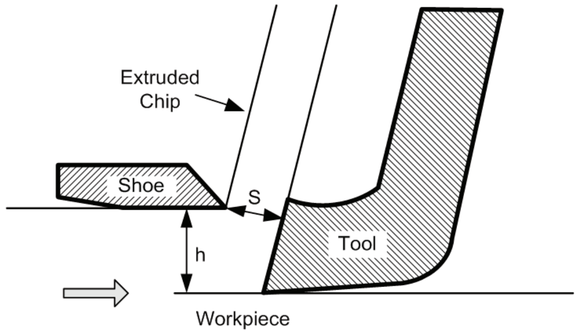

Figure 1 Extrusion-cutting produces a geometrically defined cutting process. Symbols refer to the Nomenclature [8].

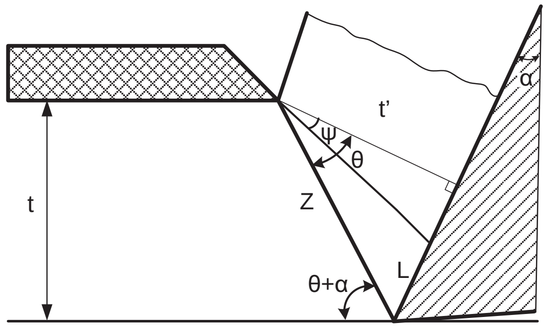

Figure 2 Upper-bound field for a shoe position near that for unrestricted cutting. Symbols refer to the Nomenclature [8].

$$\frac{p}{k} = \frac{\dot{W}}{kvhw} = \frac{\lambda}{cos\alpha} + \frac{2}{\lambda cos\alpha} - 3tan\alpha \quad (1)$$

$$\gamma = \frac{\lambda}{cos\alpha} + \frac{1}{\lambda cos\alpha} - 2tan\alpha \quad (2)$$

$$\dot{\gamma} = \frac{\gamma v sin(\alpha + \theta)}{d} \quad (3)$$

$$\Delta T = \frac{k(\dot{W}/_{kvhw})}{J\rho c} \quad (4)$$

2. Extrusion-cutting tests and generation of material data for copper

Fig. 3 shows the experimental setup for extrusion-cutting on a disk that was used for the campaign. The machine is a Mazak Nexus 200-II M CNC turning centre. A Kistler 9129 AA piezoelectric dynamometer was installed on the lathe turret for cutting force