Computational and Experimental Modelling of the Crushing of Prepared Sugar Cane

Thesis submitted by

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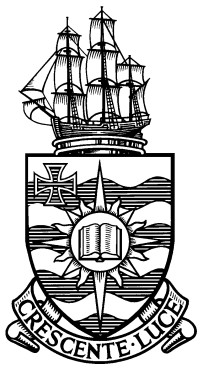

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ABSTRACT

This thesis presents the investigation and application of porous media mechanics and elasto-plastic constitutive theory for the crushing of prepared sugar cane using finite element simulation. This research specifically investigates the experiments carried out on C. R. Murry Advanced Experimental Milling Facility using cane that has also passed through a series of basic tests to characterise its properties for the computational models. For isotropic plastic material behaviour, constitutive models that represent yielding under hydrostatic pressures are applied. The constitutive behaviour of the solid skeleton, and the plastic strain hardening response are derived from a series of slow speed confined uniaxial compression experiments. The liquid flow within fibrous solid matrix of prepared cane is modelled by applying Darcy's law, and the coefficient of permeability therefore was determined experimentally.

The finite element technique applied to the crushing process, couple the elasto-plastic constitutive theory for the solid fibre and the Darcy's liquid flow theory for the liquid juice in conjunction with the frictional relation between the roller and blanket material. The material law has been coded initially into a two-dimensional plane strain computer model.

Series of experiments on two-roll mill was conducted. The two-dimensional plane strain model predicted the roll load in agreement with experimental values, however failed to capture the tangential component of compression and the torque values were 50% lower than the experimental values. However, numerical prediction of a flat roll surface matched well in roll load and torque with experimental values as the stress levels associated with grooves are absent. The rolls were then modelled with grooves in three-dimension. The three-dimensional model captured high and low compression regions in groove tip and base respectively. The roll loads as well as roll torques matched well with experimental values.

STATEMENT ON SOURCES

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

_____ Date _____

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List of symbols

α	Contact angle
α_a	Angle of contact between feed chute and rolls
α, β, γ, J	Geometrical coefficients in elliptic equation
β	Material's angle of friction
ϵ	Total strain vector
ϵ^e	Elastic strain
ϵ^p	Plastic strain
ϵ_s^p	Plastic shear strain
$\epsilon_v^p, \epsilon_v^{pl}$	Plastic volumetric strains
ϵ^t	Total strain
ϵ_h	Horizontal strain
ϵ_s	Shear strain
ϵ_s^e	Elastic shear strain
ϵ_{vn}	Volumetric strain at $C = 1$
ϵ_v, ϵ_p	Volumetric strain
ϵ_v^e	Elastic volumetric strain
ϵ_v^p	Plastic volumetric strain
$\epsilon_x, \epsilon_y, \epsilon_z$	Strains in x, y, z directions, respectively
η, μ	Dynamic viscosity
Γ	Slope of the specific volume at $p' = 0$
γ_f	Unit weight of fluid
$\gamma_{xy}, \gamma_{yz}, \gamma_{zx}$	Shear strains

κ	Slope of Swelling Recompression Line (SRL)
λ	Slope of Normal Compression Line (NCL)
μ	Friction factor
ν	Poisson's ratio
ϕ	Angle at neutral plane
ϕ	Angle of internal friction
ϕ	Slope in the τ/σ plane
ϕ'_{crit}	Soil friction angle
ρ	Density of solid-fluid mixture
ρ_c	Density of cane
ρ_f	Density of fibre
ρ_j	Density of juice
ρ_l	Density of liquid
ρ_{ng}	No gas density
ρ_s	Density of solid
σ'	Normal effective stress
σ	Total normal stress
$\sigma_1, \sigma_2, \sigma_3$	Principle stresses
σ_{av}	Average stress
σ_e	Effective stress
σ_e	von Mises equivalent stress
σ_h	Horizontal stress
σ_n	Normal stress
σ'_v	Normal effective stress
$\sigma_x, \sigma_y, \sigma_z$	Normal stresses
σ_Y	Yield stress
σ_z	Vertical stress

τ, τ_f	Shear stresses
τ_{max}	Maximum shear stress
$\tau_{xy}, \tau_{yz}, \tau_{zx}$	Shear stresses
θ	Angular position in mill measured from axial plane
θ_1, θ_2	Angular positions for roll arc surface
υ	Specific volume
υ_f	Final specific volume
υ_o	Initial specific volume
ξ, η	Computational domain coordinates
$1, 2, 3$	Spatial coordinate directions
A	Cross sectional area
A_p	Cross sectional area of test cell
A_s	Specific surface area
A_v	Cross sectional area of voids
$\hat{a}$	Treatment number
b	Length
C	Compression ratio
C_θ	Compression ratio as a function of angular position
C_c	Slope in the $e/\ln\sigma'$ plane, Corrected compression ratio
C_i	Initial compression ratio
C_o	Reference or mill compression ratio
c	Contact clearance
D	Roll diameter
d	Groove depth
d	Material cohesion
E	Extraction fraction

E, E'	Young's modulus
e	Void ratio
e_o	Initial void ratio
F	Force
F_c	Compaction
F_r	Filling ratio
F_r	Radial force
F_t	Tangential force
F_v	Vertical force
f	Fibre ratio
f_o	Reference fibre ratio
G, G'	Shear modulus
G_α	Grooving angle
g	Gravitational constant
h	Height of specimen
h	Pressure head
h_θ	Height as a function of θ
h_θ	Total height between the rolls
h_f	Height of feed chute
h_{ng}	No gas height
h_o	Blanket height
h_o	Initial height of specimen
$h_{s\theta}$	Height of solid material
i	Gradient or head loss
J_1, J_2	First and second stress invariants
K	Permeability
K	Re-absorption factor

K, K'	Bulk modulus
K_e	Effective permeability
K_o	Coefficient of lateral pressure
K_s, K_l	Bulk moduli of solid and liquid phases
k	Coefficient of permeability
k	Darcy coefficient matrix of permeability
L, l	Lengths
l_b	Cane blanket length
M	Slope of the q/p' plane
m_f	Mass of fibre
N	Torque-load number
n	Porosity
$\bar{P}$	Global liquid pressure
P	Pore pressure
P, Q	Mesh control functions
P_a	Pressure in the axial direction, psi
P_b	Yield locus
P_l	Liquid pore pressure
P_t	Total fluid pressure
p	Mean stress
p	Pressure, Contact pressure
p'	Mean normal effective stress
p_t^e	Elastic tensile stress
p_m	Mean load per unit area
p_o	Initial pressure
p_t	Tensile stress
p'_y	Yield stress

Q	Volume flow rate
q	Deviator stress
q'	Effective shear stress
$\dot{q}$	Crushing rate
R	Residual error
R	Roll separating force
S	Platen speed, Roll surface speed
S	Speed of piston
S_f	Feed velocity
S_l	Degree of liquid saturation
S_o	Set opening
S_r	Relative rubbing speed
T	Roll torque
T_{tot}	Total torque
T_x, T_y	Traction forces in x and y direction
t	Deviatoric stress measure
t	Thickness
t	time
$\ddot{u}$	Solid phase acceleration
$\dot{u}$	Global velocity vector for the solid
u	Displacement for the solid
u	Pore pressure
u_x, u_y	Displacements in x and y direction
V	Average velocity of liquid
V	Total volume or sample volume
V_b	Volume of bagasse
V_c	Volume of cane

V_f	Volume of fibre
V_j	Volume of juice
V_{ng}	No gas volume
V_{ref}	Reference volume
V_s	Volume of solid
V_v	Volume of voids
V_w	Volume of liquid
$\dot{V}_b$	Volume rate of bagasse
$\dot{V}_e$	Escribed volume rate of juice
$\dot{V}_f$	Volume rate of fibre
$\dot{V}_{je}$	Volume rate of juice
$\dot{V}_j$	Total volume rate of juice
$\dot{V}_{ng}$	No void volume rate of juice
v	Superficial velocity
v	Velocity
v_v	Seepage velocity
v_x, v_y	Velocities in x and y direction
v_y	Vertical compression speed
w	Uncertainty
w	Weighting function
$\dot{w}$	Liquid velocity vector
$w_{\mathrm{d}h}$	Uncertainty in differential head
w_{av}	Uncertainty in vertical stress
w_A	Uncertainty in area
w_c	Uncertainty in compression ratio
w_d	Work opening at delivery nip
w_f	Work opening at feed nip

w_h	Uncertainty in height of specimen
w_k	Uncertainty in permeability
w_l	Uncertainty in length
w_{ng}	Uncertainty in no gas height
w_o	Work opening
w_Q	Uncertainty in flow rate
w_{F_v}	Uncertainty in vertical force
x, y, z	Spatial coordinate directions