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Review

Ceramic tape casting: A review of current methods and trends with emphasis on rheological behaviour and flow analysis

M. Jabbari [a,*], R. Bulatova [b], A.I.Y. Tok [c], C.R.H. Bahl [b], E. Mitsoulis [d], J.H. Hattel [a]

[a] Process Modelling Group, Department of Mechanical Engineering, Technical University of Denmark, Nils Koppels Allé, 2800 Kgs. Lyngby, Denmark
[b] Department of Energy Conversion and Storage, Technical University of Denmark, Frederiksborgvej 399, Building 779, Roskilde, Denmark
[c] School of Materials Science & Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore
[d] School of Mining Engineering and Metallurgy, National Technical University of Athens, Zografou, 15780 Athens, Greece

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ABSTRACT

Tape casting has been used to produce thin layers of ceramics that can be used as single layers or can be stacked and laminated into multilayered structures. Today, tape casting is the basic fabrication process that provides multilayered capacitors and multilayered ceramic packages. In tape casting the rheological behaviour of the slurry as well as the material flow during casting are of utmost importance since these phenomena to a large extent determine the final properties and hence the quality of the cast product. During the last decades this has led to an increasing number of works in literature within fluid flow analysis of tape casting. In the present paper a review of the development of the tape casting process with particular focus on the rheological classifications as well as modelling the material flow is hence presented and in this context the current status is examined and future potential discussed.
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* Corresponding author.
E-mail address: mjab@mek.dtu.dk (M. Jabbari).

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Nomenclature

α	side flow factor
$\boldsymbol{u} \equiv \langle u, v, w \rangle$	velocity vector [mm/s]
χ, ψ	constant expressions
δ	tape thickness [mm]
$\dot{\gamma}$	shear rates [1/s]
$\dot{\gamma}_m$	local shear rate [1/s]
λ	material constants
μ	dynamic viscosity [Pa·s]
μ_0, μ_∞	material constants
$\mu_p(0)$	solvent viscosity [Pa·s]
$\mu_p(\phi)/\mu_p(0)$	relative viscosity [Pa·s]
μ_a	apparent viscosity [Pa·s]
μ_B	Bingham viscosity [Pa·s]
μ_c	Casson viscosity [Pa·s]
μ_m	matrix viscosity [Pa·s]
μ_s	local surrounding viscosity [Pa·s]
ϕ	particle volume fraction [–]
ρ	density [kg/m^3]
τ	shear stress [Pa]
τ_0^B	Bingham yield stress
τ_y	yield stress [Pa]
II	second invariant
T	stress tensor [Pa]
$\mathbf{V}_s$	settling velocity [m/s]
θ	reservoir tapered angle [deg]
$\underline{\underline{\dot{\gamma}}}$	shear rate tensor [Pa·s]
$\underline{\underline{\dot{\gamma}}}_c$	critical shear rate [1/s]
$\underline{\underline{\tau}}$	shear stress tensor [Pa]
ϖ	pressure/viscous ratio
a	particle diameter [μm]
a	Yasuda model constant
A_0, A_1, A_2	integral constants
d	reservoir length [mm]
g	gravity acceleration [m/s^2]
h	doctor blade height [mm]
H_0	initial slurry height [mm]
k	consistency of fluid [Pa · s^n]
l	reservoir tapered length [mm]
n	power-law index
p, P	pressure [Pa]
t	time [s]
v_0	casting speed, substrate velocity [mm/s]
v_{cr}	critical velocity [mm/s]
W	doctor blade width [mm]
w_s	side flow length [mm]

1. Introduction

Tape Casting was first introduced in the 1940s during the Second World War when there was a serious lack of quartermaster materials to produce mica capacitors [1]. In tape casting, sometimes referred to as the doctor-blade process, the slurry is spread over a surface using a carefully controlled blade referred to as a doctor blade. As a result, films of up to hundreds meters in length and as thin as 1 μm can be obtained, and they can be as thick as 3000 μm [2–4]. A schematic of the tape casting process from the beginning of the powder preparation over the casting itself to the final stage of drying, is illustrated in Fig. 1. The tape casting process was firstly reported publicly in 1947 by Howatt et al. [1] to produce thin ceramic sheets for usage of capacitor dielectrics, and was shortly after applied to industrial production of ceramic capacitors [5].

Years after in 1967, Stetson and Gyurk [6] prepared alumina (Al_2O_3) substrates by tape casting, which were used as substrates for thin film circuits, devices, and integrated circuits. Meanwhile, Schwartz and Kirkpatrick [7] together with the IBM corporation developed a layer packaging material for use in computers by means of the tape casting process. In the 1970s many new products were successfully developed and a number of tape casting applications emerged [8–10]. Many works on materials development and process improvement were published in the 1980s–1990s, see for example [11–19]. Basically this era was a period in which the technology matured and new applications were explored, such as the production of thin membranes for fuel cells [20,21]. Most of the work later on is dedicated to different material investigations and development of different products by means of tape casting as well as more recently, theoretical analysis of the process by means of numerical modelling.

As an example on material synthesizing, Moreno has studied the role of slip additives in the tape casting process, mainly solvents, dispersants, binders and plasticizers [22–24]. Hotza and Greil reviewed the slurry formulations and processing parameters

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