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Modelling the influence of the gas to melt ratio on the solid fraction of the surface in spray formed billets

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Abstract

In this paper, the relationship between the Gas to Melt Ratio (GMR) and the solid fraction of an evolving billet surface is investigated numerically. The basis for the analysis is a recently developed integrated procedure for modelling the entire spray forming process. This model includes the atomisation stage taking thermal coupling into consideration and the deposition of the droplets at the surface of the billet taking geometrical aspects such as shading into account. The coupling between these two models is accomplished by ensuring that the total droplet size distribution of the spray is the summation of "local" droplet size distributions along the *r*-axis of the spray cone. The criterion for a successful process has been a predefined process window characterised by a desired solid fraction range at a certain distance from the atomizer. Inside this process window, the gas and melt flows have been varied and their influence on the solid fraction at the surface of the billet has been analysed.

Keywords: Spray forming; Atomisation; Deposition; Gas to Melt Ratio; Process window

1. Introduction

Although the spray forming process has been subject to intensive research during the last two decades, many important features remain unexplored. An enhanced understanding of the process should permit development of predictive models elucidating the interrelationships between the process/structure/properties and performance.

The spray forming process has been continuously modelled and described in literature. The models are often divided into two parts namely: atomisation and deposition. A major part of the models for atomisation are based on the idea that the continuous phase (gas) affects the properties of the dispersed phase (liquid melt) but not vice versa [1,2]. However, in a real system the droplets, which are represented by their size distribution do interact with each other via the gas and therefore a model that is able to reflect that, is desirable.

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Nomenclature

A_g	area of gas delivery nozzles [m]
c_p	specific heat capacity [J Kg^{-1} K^{-1}]
c_p^*	adjusted specific heat capacity [J Kg^{-1} K^{-1}]
d	droplet diameter [m]
$d_{50,k}$	mean droplet diameter of local distribution k [m]
$\mathbf{e}_n$	unit vector normal to the preform [m]
$\mathbf{e}_f$	unit vector along the line between surface point and the atomiser [m]
$\mathbf{e}_x$	unit basis vector [m]
$\mathbf{e}_y$	unit basis vector [m]
$\mathbf{e}_z$	unit basis vector [m]
d_m	mass median diameter of droplets [μm]
d_0	liquid stream diameter [μm]
D_0	distance from the atomizer to the surface of the billet [m]
f_s	solid fraction [–]
f_l	fraction liquid of spray [–]
F_l	fraction liquid of preform [–]
i	index for droplet diameter [–]
J_g	mass flow rate of gas [kg s^{-1}]
J_l	mass flow rate of liquid [kg s^{-1}]
k	thermal conductivity [W m^{-1} K^{-1}]
k	index for local distribution [–]
K_a	experimental constant in (1) [m]
$\dot{m}$	mass flow of droplets in diameter interval [kg s^{-1}]
$\dot{M}(r,z)$	mass flux distribution in spray cone [kg s^{-1} m^{-2}]
$\dot{M}_{\text{Total}}$	total mass flow in spray cone [kg s^{-1}]
r	spatial coordinate [m]
SE	sticking efficiency [–]
t	time [s]
T	temperature [K]
T_{sol}	solidus temperature [K]
T_{liq}	liquidus temperature [K]
T_M	solvent melt temperature [K]
T_E	eutectic temperature [K]
P_k^{local}	local droplet distribution [–]
We	Weber number [–]
x	spatial coordinate [m]
y	spatial coordinate [m]
z	spatial coordinate [m]

Greek symbols

α_s	parameter in (4) [–]
α_l	parameter in (4) [–]
ΔH_f^{Left}	remaining freezing enthalpy [J kg^{-1}]
ε	parameter in (4) [–]
η_g	kinematic viscosity of gas [Pa s]
η_l	kinematic viscosity of liquid [Pa s]
ρ	density [kg m^{-3}]
σ	standard deviation [–]
θ	spatial coordinate [–]
ξ	shading function [–]