Experimental Investigation and Modeling of the Specific Enthalpy Distribution in a Spray Cone

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Abstract

In Spray Forming, specific enthalpy is a key parameter in the deposition process as it influences the thermal condition of the impinging droplets as well as that of the deposit surface. An empirical model for the distribution of specific enthalpy in the spray cone was developed as an easy to handle alternative to numerical models with which the descriptive partial differential equations are solved numerically. The model results were compared with the experimental data to validate its applicability.

Keywords: atomization; droplet solidification; enthalpy model

1. Introduction

In Spray Forming, specific enthalpy in the spray is a key parameter in the deposition process as it influcuences the thermal condition of the deposit surface as well as that of the droplets. The distribution of specific enthalpy after atomization has been modeled for different sprays. Most existing models are either based on analytical solutions of describing partial differential equations in simplified cases or based on solving these equations numerically. For two phase atomization processes, the latter class of the model is commonly used [1,2], because the thermal coupling between the two phases has to be taken into account [3]. For the simulation of deposit growth and the thermal history of a deposit, a simultanous computation of deposit growth and the enthalpy distribution in the spray is necessary, as the thermal condition of the droplets influence the deposition process.

In this paper, an empricial model based on enthalpy measurements [4] was developed to simplify the calculation of specific enthalpy for a free fall nozzle system. The model is based on the model for the distribution of mass flux in the spray cone [5].

2. Experimental Procedure

Buchholz [4] have taken measurements of specific enthalpy in the spray have been conducted by for Copper, the bronze alloys Cu-6wt% Sn and Cu-15.5wt% Sn as well as for the steels AISI52100 and a low carbon steel C35.

Fig. 1 shows a scheme of the spray forming plant used for the measurements of specific enthalpy. Metal was melted in a crucible (1). The melt was held at a contant temperature while being continuously poured into the tundish (2) to maintain a constant melt level. The melt was then flowed through the outlet and atomized using a free-fall atomizer (3). The particles were made to cool down during their flight. The substrat was hit to form a deposit.

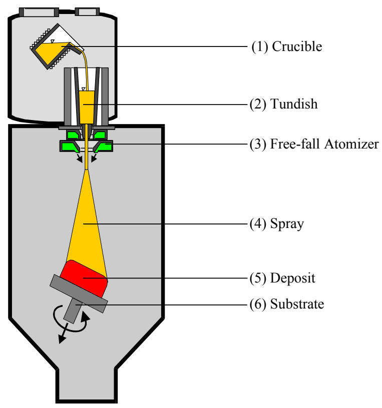


Fig. 1. Schematic of the spray forming plant used for the enthalpy measurements

3. Parameters on the Distribution of Specific Enthalpy and Model Simplifications

- The distribution of specific enthalpy is a function of a specific melt of the enthalpy that is assumed to be equal in the crucible and at the nozzle distance z=0
- The mass median particle diameter derived by Lubanska [8] is a measure for the convective heat loss, the surface to volume ratio of the particles and for the initial load of the spray
- The position in the spray cone described by cylindrical coordinates (r,z)
- Material properties of the chosen metal and atomization gas

4. Model Equations

The decrease of the average specific enthalpy in the spray cone $\overline{h}$ (z) and the maximum specific enthalpy h_0(z) on the center axis is described by the equations

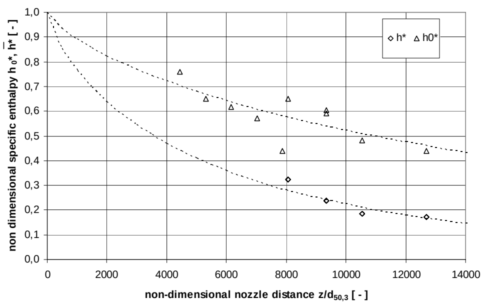
$$\overline{h}(z) = h_\infty + (h_{melt} - h_\infty) \cdot \exp\left(a_1 \cdot z^{b_1} \cdot d_{50,3}^{c_1}\right)$$
$$h_0(z) = h_\infty + (h_{melt} - h_\infty) \cdot \exp\left(a_2 \cdot z^{b_2} \cdot d_{50,3}^{c_2}\right)$$

For the radial distribution of specific enthalpy at the nozzle distance *z*, it is assumed that the type of distribution is similar to the radial distribution of mass flux.

$$h(r)\big|_z = h_\infty + \left(h_0(z) - h_\infty\right) \cdot \exp\left[-\ln(2) \cdot \left(\frac{r}{r_{0.5,h}}\right)^{k_h}\right]$$

The definition of the radial distribution includes the half radius $r_{0.5,h}$, which is the radius at which the specific enthalpy is decreasesd to half of its peak value and can be determined by using an energy balance for the spray cone.

5. Results



Alloy	a_1 [-]	a_2 [-]	h_∞ [J/kg]	All Alloys:
Cu	$-1.5\cdot10^{-3}$	$-0.65\cdot10^{-3}$	40	$b_1=b_2=0.75$ [-]
CuSn6	$-1.7\cdot10^{-3}$	$-0.57\cdot10^{-3}$	80	$c_1=c_2=0.75$ [-]
CuSn13.5	$-1.1\cdot10^{-3}$	$-0.7\cdot10^{-3}$	40	$k_h=1.8$ [-]
C35	$-1.15\cdot10^{-3}$	$-0.19\cdot10^{-3}$	80	

Fig. 2. Measured Data of non-dimensional maximum specific enthalpy (h_0*) and average specific enthalpy ($\overline{h}$*) on the center line during the atomization of copper (top) and model constants (bottom)

Fig. 2 shows the experimental data and the fitted model for the axial decrease of maximum and average specific enthalpy during the atomization of copper. It can be seen that the data fits the model well. A list of model constants for different steel, copper and bronze melts is also given.

Fig. 3 shows the measured radial distribution specific enthalpy for copper, the bronze CuSn13.5 and the steel 100Cr6 as well as the model curve. Even if the model curve does not fit the data perfectly, the energy balance that was used to calculate the width of the distribution shows that the total enthalpy content of the spray is correct.

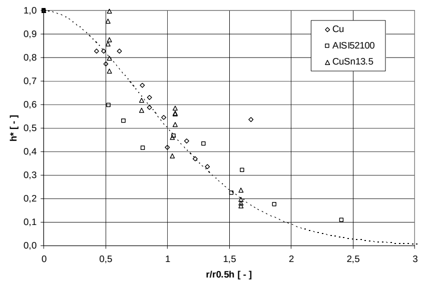


Fig. 3. Radial distribution of specific enthalpy for the atomization of Cu, bronze CuSn13.5 and the steel AISI52100

6. Summary

A model for the distribution of specific enthalpy in a spray cone was developed based on an existing mass flux model. The model was formulated in a way that the radial distribution can be derived from the axial decrease of maximum and average enthalpy using an energy balance, so that the total energy content in the spray is correct. The model was applied using the experimental data measured with caloric probes for different copper, bronze and steel melts and process conditions. The model was found to fit well with the data, hence showing that it can be a useful tool for practical estimations of the influence of process parameters on the enthalpy in the spray cone, which is – in the case of melt atomization – related to an average solidification degree in the spray.

7. References

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