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Original Research Paper

Influence of water pressure and apex angle on prediction of particle size for atomization of copper powder

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ABSTRACT

Water atomization can be used to produce wide range of particle size, shape and particle size distribution of metal powder efficiently by varying operating variables which include design parameters, process parameters and thermophysical properties of metal and water. Liquid copper was water atomized in a laboratory fabricated atomizer. Few experiments were conducted to produce copper powder by varying water jet pressure. In the present work, mathematical model was formulated to propose a relationship between particle size of copper powder and operating variables. Proposed mathematical model is developed to predict particle size affected by different parameters and validated with experimental results. 3-D surface response was analyzed by varying water pressure and apex angle.

1. Introduction

In water atomization process, a number of operation variables are to be considered in order to properly control the process. The variables include geometry parameters, process parameters and thermophysical properties of metal and water. Each design and configuration of atomization unit is unique and thus only some specific operation conditions may be employed and many of these variables are interrelated [1]. Therefore, there may exist more than one set of optimum variable combinations for a given atomization unit. Several studies have shown that the pressure of the atomizing water has significant effect on the atomized particle size, as reported by Persson et al. wherein water pressure from 8 to 17.5 MPa during atomization of Fe–C alloy in a laboratory atomizer decreased particle size by 45–50% [2]. Effect of increasing apex angle on decreasing particle size is also observed. Yenwiset et al. showed that high heat temperature level of liquid metal, flow rate of liquid metal and water pressure directly affected average sizes of produced copper powder particles [3]. Rajgure has designed and developed an atomizer using closed V-jet type nozzles [4]. The existing mathematical models derived for prediction of particle size in powder atomizer are limited and those are comprised of two to nine variables [5–12]. However in the present research work, a mathematical model is proposed for prediction of powder size which comprise of thirteen parameters affecting particle size during water atomization.

2. Experimental work and procedure

In the present work, a laboratory fabricated water atomizer was used for atomization of copper powder. Only water pressure and water flow rate were varied by keeping other parameters unchanged such as superheat temperature (150 °C), melt flow rate ($7.832 \times 10^{-6}\ m^3/s$), apex angle (45°). Water jet system was designed and attached to an atomizer chamber as shown below in Fig. 1. A closed V-jet type nozzle assembly was used in this atomizer chamber, directing the water jets at a concentric point along the axis of metal stream (freely falling under gravity). In order to vary pressure of water jet, a small control system consisting of pressure gauge and control valve were attached to the water pipe line. Copper metal was superheated by 150 °C above melting point (1506 K) in induction furnace (25 KW). The liquid copper was then poured into hot crucible (800 °C) closely fitted on the top of the nozzle assembly. The liquid metal makes a stream falling through the 3 mm bottom nozzle provided to the crucible. Stream of liquid metals passes through a high impact zone created by water jets through nozzles mounted at an angle of 45°. The water pressure was varied from 10 psi to 40 psi at an equal interval. After the atomization wet powder was dried in a furnace at 120 °C. Then it was characterized by sieve size analysis using sieves of different mesh to get powder particle size distribution.

3. Formulation of dimensionless particle size model (DPSM)

In the present work, it was postulated that copper powder particle size is affected by the various process parameters as described

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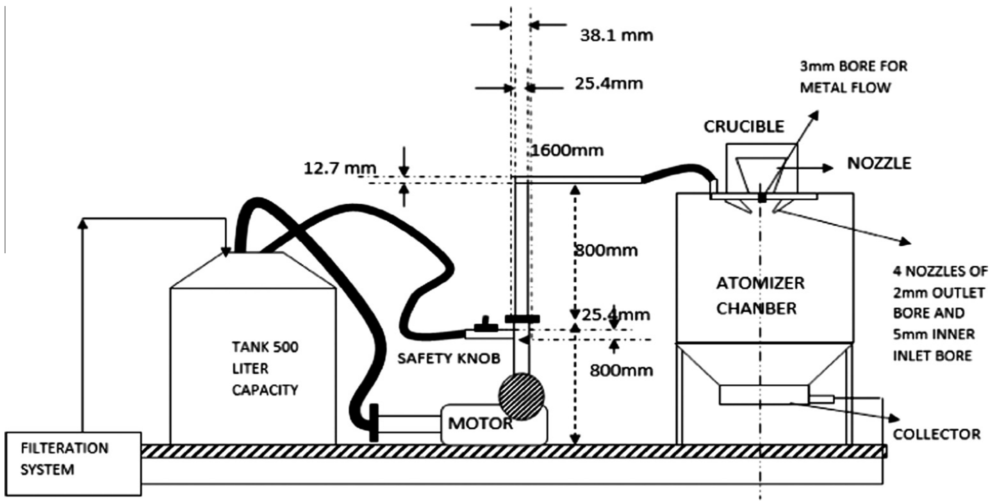

Fig. 1. Schematic sketch of laboratory fabricated water atomizer.

in Table 1 and its relationship was expressed by Eq. (1). This can be solved by using Buckingham's Pi theorem. It is stated that dimensionally homogeneous equation involving 'n' variables in 'm' primary or fundamental dimensions can be reduced to a single relationship among n–m independent dimensionless products [13]. The final form of the model is given by Eq. (2) and detailing of the steps is given in Appendix A.

$$D = f(P, Q_w, Q_m, \rho_w, \rho_m, \rho_p, T_{mp}, T_{superheat}, \eta_m, h_f, C_p, L) \tag{1}$$

The corresponding DPSM equation is

$$\frac{D}{L} = \emptyset\left[\frac{L^{13} \times Q_m \times \rho_w \times \rho_p \times T_{mp} \times \eta_m \times h_f \times C_P}{\rho_m^4} \times \frac{P}{Q_w^8}\right]^A \tag{2}$$

$$Y = \emptyset X^A \tag{3}$$

3.1. Terminology

Dimensionless particle size parameter (Y) is the ratio of diameter of the particle (D) to the length of interaction (L). Thus length of interaction is a function of apex angle and distance between the principle axis of the liquid metal stream and the position of the nozzle. The schematic explanation of the parameters involved is shown in Fig. 2 and their inter-relationship is given by Eq. (4).

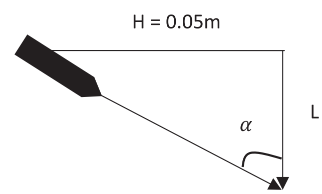

Fig. 2. Relationship of apex angle with length of interaction.

$$L = \frac{H}{\tan\alpha} \tag{4}$$

Dimensionless process parameter (X) is defined by Eq. (5) consists of number of variables affecting the particle size while atomization of liquid metal. It is a combined interactive process parameter. Any interaction amongst the variables configured in X is reflected in terms of exponent A.

$$X = \frac{L^{13} \times Q_m \times \rho_w \times \rho_p \times T_{mp} \times \eta_m \times h_f \times C_p}{\rho_m^4} \times \frac{p}{Q_w^8} \tag{5}$$

Table 1
Abbreviations of symbols and their dimensional forms.

Sr. no.	Description of parameters	Symbols	Units	Dimensional form
1	Average particle size[a]	D	m	$[M^0L^1T^0\theta^0]$
2	Pressure of water	P	N/m^2	$[M^1L^{-1}T^{-2}\theta^0]$
3	Flow rate of water	Q_w	m^3/s	$[M^0L^3T^{-1}\theta^0]$
4	Flow rate of melt	Q_m	m^3/s	$[M^0L^3T^{-1}\theta^0]$
5	Density of water	ρ_w	kg/m^3	$[M^1L^{-3}T^0\theta^0]$
6	Density of melt	ρ_m	kg/m^3	$[M^1L^{-3}T^0\theta^0]$
7	Density of powder particle	ρ_p	kg/m^3	$[M^1L^{-3}T^0\theta^0]$
8	Melting temperature of metal	T_{mp}	K	$[M^0L^0T^0\theta^1]$
9	Superheat temperature of melt	$T_{superheat}$	K	$[M^0L^0T^0\theta^1]$
10	Viscosity of melt	η_m	kg/ms	$[M^1L^{-1}T^{-1}\theta^0]$
11	Heat of fusion of melt	h_f	J/kg	$[M^0L^2T^{-2}\theta^0]$
12	Heat capacity of melt	C_p	J/kg.K	$[M^0L^2T^{-2}\theta^{-1}]$
13	Length of interaction	L	m	$[M^0L^1T^0\theta^0]$
14	Actual particle size	D_A	m	$[M^0L^1T^0\theta^0]$
15	Predicted particle size	D_P	m	$[M^0L^1T^0\theta^0]$

[a] $D = \frac{\sum(W \times M)}{\sum(W)}$, where W = weight of powder retained on particular sieve size, M = mid value of class interval of sieve size.