Mechanism and Performance of a Novel Atomizer for Metal Powder Production with Supersonic Configuration

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Abstract

A novel internal-mixing atomizer was designed to produce metal powder at lower gas pressure (up to 4 bar) with convergent-divergent configuration to achieve supersonic atomization. The atomization mechanism was investigated by high speed photography. The atomization performance was characterized by atomization of water and melt of copper for the parametric study. Results show that median mean particle size \(d_{50}\) of 8.22 \(\mu m\) can be achieved with water. The copper powders with median mean particle size \(d_{50}\) of 64.83 \(\mu m\) were obtained which is in spherical shape.

Introduction

Metal powders have been widely used in powder metallurgy (PM), metal injection moulding (MIM) and laser forming to produce near-net shape parts. They are also used to form coatings on substrates by thermal spraying and cold spraying processes. There are four categories for the production of metal powders based on mechanical comminution, chemical reaction, electrolytic deposition, and molten metal atomization [1]. Among these methods, atomization technique has been taken as the major method due to its high production rate and possibility to control the size, size distribution, shape and morphology. Rapid solidification of droplets in atomization process is also beneficial for producing fine-scale microstructure powders.

Two-fluid atomization, including water atomization and gas atomization, is the most common method of atomizing metals on an industrial scale. Water atomization is used for high production rate process with lower cost. The particles produced by water atomization, however, are irregular and with higher oxygen content. Gas atomization is used to produce spherical powders with lower contamination by atomizing melt with inert gas.

Typically, there are two common types of gas atomizer, namely free fall atomizer and closed-coupled atomizer [2] and the schematic diagram is shown in Figure 1. The free fall atomizer allows the melt stream to flow a distance from 100 to 200 mm downward the nozzle tip before high velocity gas impinging on it. It has the advantages to avoid freezing-off at the nozzle tip and easy operation. However, the gas jets in free fall atomizer don’t impinge on the melt stream instantly, which may cause energy loss and result in lower efficiency. Hence the free fall atomizer is not suitable for fine powder production [3]. In closed-coupled atomization process, the gas jets impinge on the metal stream at the point where it emerges from the delivery or guide tube. This configuration is suitable for efficient atomization and the production of fine powders because: (a) the gas jets can be positioned very close to the emerging metal stream and (b) the gas streams can be directed at the metal stream at a high angle of attack [4]. In the past thirty years, several close-coupled atomizers have been worked out and the mechanism and performance have been studied [5,6,7]. These atomization processes, however, are operated at high gas pressure (typically above 2 MPa) which means higher cost for the higher gas consumption. In contrast, the concept of internal mixing atomizer is to mix high velocity gas with liquid in the atomizer. Studies have shown that internal mixing atomizer is capable of fine metal powder production at low pressure and gas consumption [8]. However, melt needs to be pressurized in internal mixing atomization process; therefore, some problems may occur due to the pressurized processes of high temperature medium in the container.

In the present study, a novel internal mixing atomizer has been developed for metal powder production under low gas atomization pressure. Liquid was delivered to the atomizer by gravity and aspiration processes at the nozzle tip. Water was used as the atomization medium to investigate the mechanism of the atomizer. The effect of gas atomization pressure and inner diameter of delivery tube on droplets size was also investigated. Furthermore, molten copper was atomized to investigate the performance of the internal mixing atomizer for metal powder production.

Experimental Setup

The atomizer developed in the presented work is based on an internal-mixing design concept with lower gas pressure, as shown in Fig. 2. In the atomizer, gas flowed through a convergent – divergent section constructed by the atomizer body and the nozzle and was accelerated to supersonic speed at the nozzle tip. The throat area of the annular flow channel was 46.7 mm², and the area ratio of the exit of nozzle to throat was 1.9. To investigate the performance of the atomizer, experiments were first carried out with water. Air was used as the atomizing agent...
in order to understand the atomization mechanism of the internal mixing atomizer. An acrylic atomizer was used for flow visualization and a high speed camera (IDT) was used to investigate the interaction between gas and water at several stages of the atomization process. The atomization efficiency was determined by atomizing water and the experimental equipment is shown as Figure 3.

Figure 2. Schematic of supersonic internal-mixing atomizer

The gas atomization pressure was set by the gas regulator and the flow rate was measured by a rotameter. The water droplet size was analyzed by a real-time measurement with INSITEC RT-Sizer at a downstream distance of 10 cm from the atomizer exit. The gas pressure was controlled under 1 to 4 bar so that the gas flow left the channel at overexpanded condition. The inner diameter of the delivery tube was 2 mm to 4 mm. Atomization of melt was performed by atomizing molten copper to understand the performance of the atomizer for metal powder production. Copper was melted by an induction heater in a crucible and flowed through the delivery tube to form spray when the stopper rod in the crucible was pulled up. The copper powder was then collected and powder size was analyzed by Coulter-LS230 particle size analyser and the powder morphology was determined by scanning electron microscopy (HITACHI S-3000N).

Figure 3. Schematic of the equipment in water atomization experiments: (1) atomizer, (2) crucible, (3) INSITEC RT-Sizer (4) A/D converter, (5) computer, (6) Air reservoir, (7) flowmeter, (8) regulator, (9) water supply, (10) ventilator

Results and Discussion

Atomization Mechanism

The interaction between gas and liquid inside the internal-mixing atomizer and the downstream flow pattern at the exit of the atomizer were observed by a high speed camera in order to understand the atomization mechanism of the novel atomizer. The gas pressure was fixed at 4 bar and the inner diameter of delivery tube was 2 mm. In the experiments, water was firstly poured into the crucible and the water stream flowed out the nozzle by gravity. The water stream was developed into the water spray as the gas flow was introduced to the atomizer with valve opened. The images were recorded by the high speed camera as shown in Figure 4. It can be observed that, at the beginning of the atomization processes at t = 5 ms, the liquid stream was first impinged by gas flow at a distance downstream from the nozzle tip and disrupted into two sections (see Figure 4(a)). Liquid in the downstream of the impingement point was then atomized; however, liquid in the upstream was draw back to the nozzle tip by recirculation flow caused by the atomization gas (see Figure 4(b) and (c)). The recirculation and the aspiration at the nozzle tip were still weak owing to the low velocity gas under lower gas pressure. Hence the liquid was accumulated at the nozzle tip and cannot be spread to form a thin liquid film (Figure 4(d) to (f)). As a result, the atomization performance was worse at this beginning stage.

Figure 4. Evolution of atomization processes at the beginning stages
After a period of time, the liquid stream was accumulated at the nozzle tip. The recirculation zone was suddenly moved upstream along the surface of the nozzle at the divergent section. This can be observed as water was suddenly drawn upward near the throat of the flow channel, as shown in Figure 5. Water was then pushed back to the nozzle tip at $t = 73$ ms. As the gas pressure was further increased, the gas flow reached sonic speed through the convergent section. However, the pressure ratio of the instantaneous gas pressure to back pressure was not high enough at this moment and a shock occurred at the divergent section to adjust the static pressure to meet the back pressure. The shock changed the flow direction and the gas flow no longer attached to the divergent surface of the nozzle; therefore, the space between the gas flow directed after shock and the nozzle became an upward extension of the recirculation zone. As the instantaneous gas pressure further increased, the shock moved downstream along the divergent section and the recirculation zone moved back to the nozzle tip. After the shock moved out the divergent flow channel and the starting gas pressure reached the setting gas pressure, the pressurized period was over and the spray was performed at the atomization period.

Figure 5. Movement of water in the recirculation zone

![Recirculation Zone Movement](image)

The flow pattern at the atomization period determines the performance of the atomizer because whole atomization process is performed at this condition. As shown in Figure 6, gas flow downstream the nozzle tip may change as shown in Figure 6. It can also be observed that the gas flow was further expanded as it flowed out the atomizer and the spray formed a “neck” flow pattern. Mates and Settles mentioned that there are two type of primary breakup mechanism in liquid atomization as “melt sheet” and “fountain” primary breakup models, as shown in Figure 7 [5]. The primary breakup mechanism of the internal-mixing atomizer designed in the present study may be a combination of the two models, since the liquid stream flowed a certain distance out of the nozzle and liquid film still occurred by the recirculation. The instability of the liquid stream can also be observed, since the liquid stream may be centered in the middle of the recirculation zone or attached to both sides of the liquid film.

Figure 6. Two kinds of flow patterns during atomization process

![Flow Patterns](image)

Figure 7. Primary breakup models of “melt sheet” and “fountain” [5]

**Atomization Performance**

In the internal-mixing atomizer studied in this research, the liquid was forced to flow through the delivery tube by the pressure difference between the bottom of the crucible and the exit of the nozzle tip plus gravity. Therefore, the aspiration pressure at the nozzle tip determines the liquid flow can be atomized or not and was investigated firstly at different gas pressure, as shown in Figure 8. The aspiration increases as gas pressure increasing from 1 to 4 bar. The aspiration at the nozzle tip is caused by the recirculation zone as high velocity gas flows out of the convergent-divergent channel. As a result, the recirculation is stronger as the gas velocity increases owing to the increase of gas pressure.
The atomization characteristics of the atomizer were firstly investigated by atomizing water to have a whole observation on the efficiency of the new atomizer. Figure 9 shows the dependency of median particle size $d_{50}$ on gas pressure at different inner diameters of delivery tube. It can be observed that the median particle size decreases with increasing gas pressure. As the inner diameters of the delivery tube decreases from 4 mm to 2 mm, $d_{50}$ decreases from 17.91 $\mu$m to 8.22 $\mu$m at gas pressure of 4 bar. The gas velocity increases as gas pressure was increased. Hence the gas flow offered more kinetic energy for the disruption of the liquid film or ligaments. As a result, fine particles can be obtained at higher gas pressure. In addition, the influence of inner diameter of delivery tube can also be observed in Figure 9. Better atomization performance is achieved by reducing the inner diameter of delivery tube. Since the kinetic energy is the same at same gas pressure, atomization with less liquid flow rate at smaller inner diameter of delivery tube results in better performance.

In the melt experiment, copper was atomized to investigate the performance of the internal-mixing atomizer to produce metal powders. The gas was 4 bar and the inner diameter of the delivery tube was 2 mm. The median particle size was 64.83 $\mu$m and the size distribution was shown in Figure 10. The morphology of the atomized particles is shown in Figure 11. The particles were generally spherical as shown in the SEM photographs. As a result, the supersonic internal-mixing atomizer is capable for production of metal powders at low cost.

Conclusions

A novel internal-mixing gas atomizer was studied by investigating the atomization mechanism and performance. Flow pattern was observed and a movement of recirculation zone was found owing to the downward movement of internal shock at the divergent section as the gas increasing at the pressurization period. The change of gas flow area is caused by the existence of internal shock and expansion waves. The atomization performance is investigated by atomizing water and copper melt. Fine and spherical copper powders are obtained. As a result, the atomizer is capable for metal powder production.

References


