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DEVELOPMENT OF INDIGENOUS LABORATORY SCALE GAS ATOMIZER FOR PRODUCING METAL POWDERS

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Gas atomization is one of the methods for production of clean metal powders at relatively moderate cost. A laboratory scale gas atomizer was designed and fabricated indigenously to produce metal powders with a batch capacity of 500g of copper (Cu). The design includes several features regarding fabrication and operation to provide optimum conditions for atomization. The inner diameter of atomizing chamber is 440 mm and its height is 1200 mm. The atomizing nozzle is of annular confined convergent type with an angle of 25^o. Argon gas at desired pressure has been used for atomizing the metals to produce relatively clean powders. A provision has also been made to view the atomization process. The indigenous laboratory scale gas atomizer was used to produce tin (Sn) and copper (Cu) powders with different atomizing gas pressures ranging from 2 to 10 bar. The particle size of different powders produced ranges from 40 to 400 µm.

Keywords: *Gas atomizer, Indigenization, Design features, Metal powder fabrication*

1. Introduction

Powder metallurgy (P/M) is the production, processing and consolidation of fine metal particles into a usable engineering component. For many years a large well established P/M industry involving materials such as iron (Fe) and copper (Cu) has been in existence [1]. The driving factors include cost reduction, feasibility for almost all materials and ability to produce unique alloy microstructures and properties [2,3]. Metal powders, therefore, have a wide range of applications including automotive components, controlled porosity components, biomedical components, cutting and wear applications, electronic and magnetic sensors, nuclear applications etc. Automotive sector covers about 70% of P/M applications [2].

Different methods are used to form metal powders. In all methods energy is delivered to create surface area thus increasing the surface energy [2]. Atomization is one of the most commonly used production technique for metal powders. Atomization involves melting of desired metal followed by break up of molten metal stream into small droplets. This break up may be obtained by impingement of a high velocity jet of gas (gas atomization) or water/oil (liquid atomization). Similarly, liquid metal may be broken into particles by use of centrifugal force (centrifugal atomization) or by exposure to a vacuum (vacuum atomization) [4].

Inert gas atomization offers a moderate cost, moderate distribution of particle size, high purity, and spherical particle shape. It provides a very good compromise between cost and purity of powder produced. The particle size typically ranges from 15-300 µm [2]. It is one of the metal powders fabrication technique amenable to commercial production [5].

A typical gas atomizer configuration is shown in Figure 1. The atomization is carried out in an enclosed chamber filled with inert gas so as to confine powder particles and prevent any oxidation of powder particles. Gases used usually include N_2 or Ar. Generally, two types of nozzle arrangements are used in gas atomizer, free-fall nozzle arrangement and confined nozzle arrangement. In free fall nozzle arrangement molten metal falls freely in form of a stream and atomizing gas jets strike the molten metal stream at a certain angle to atomize it [3]. In confined nozzle arrangement molten metal is fed through a central tube that is

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surrounded by a coaxial gas nozzle. The nozzle generates a high velocity gas stream that disintegrates the slower melt stream into fine droplets. These droplets then freeze in-flight into solid powder particles [6].

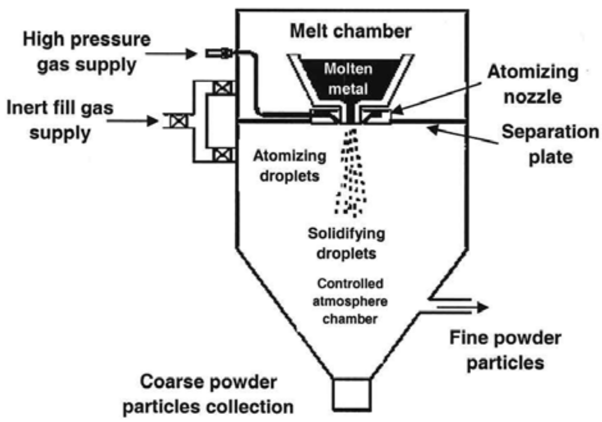

Figure 1. Schematic view of a typical Gas Atomizer [6].

Inert gas atomization requires a number of parameters to be optimized which affect the powder product. Some of the important parameters include geometry of atomizing nozzle, gas pressure, heat capacity of inert gas, degree of superheating of metal above its melting temperature, gas-to-metal flow ratio, etc. [5]. Heat transfer to molten metal in teeming nozzle is the most critical issue because liquid metal can easily freeze inside it and interrupt atomization. Therefore, teeming nozzle should thermally insulate the molten metal. Moreover, it should be chemically inert to reduce or avoid contamination and erosion [6].

Metals atomized commercially range from Sn and Sn-Pb alloys to Al, steel and Ni-based alloys. Gas atomized powders are used as rocket propellant additives, chemical catalysts, feedstock for P/M consolidation and thermal spray coatings and in many other applications [6].

A laboratory scale indigenous gas atomizer has been designed and fabricated. The objective was to add facility for metal powder fabrication, for R & D and production purposes. The present paper discusses different aspects of design and operation of indigenous gas atomizer for metal powder fabrication with different attributes.

2. Design Requirements

There are certain design requirements which have been identified as essential design features of a gas atomizer for its successful operation. These design requirements were sorted out from literature [4-11] and are given below;

i. The molten metal should not freeze in the teeming nozzle as it interrupts the atomization process.

ii. The size of the atomizing chamber should be sufficient to allow in-flight solidification of molten droplets of metal before striking the walls of chamber.

iii. The atomizing nozzle should be of confined annular type with angle ranging between 12^o-26^o and a reasonable gas exit opening so as to produce an annular gas jet.

iv. There should be some mechanism to separate powder from atomizing fluid (air/gas).

v. The whole system should be leak tight.

vi. There should develop an aspiration effect at metal exit of atomizing nozzle.

vii. There should be provision for a vent (exhaust) line to avoid over-pressure inside the atomizing chamber, considering the safety issues.

3. Description of Atomizer Assembly

Keeping in view above mentioned design requirements, the atomizer assembly consisting of seven main components was fabricated. The components include atomizing chamber, supporting lid, atomizing nozzle and plenum chamber assembly, melting crucible & teeming nozzle assembly, an induction generator, cyclone separator, and powder collector. The height of entire assembly is about 1650 mm. The whole assembly is supported on a platform. The platform provides access to the main components and facilitate during the atomizer operation. A schematic of the atomizer assembly is shown in Figure 2.

3.1. Atomizing Chamber

Atomizing chamber consists of two sections i.e. cylindrical chamber and conical chamber. Both of these chambers are made of rolled stainless steel sheet fitted with flanges. Cylindrical section has internal diameter of about 440 mm. The overall height of cylindrical and conical sections is about

1200 mm. All of the internal surfaces of atomizing chamber were buffed and polished to facilitate cleaning of chamber between runs of different metals. A view port is provided in the cylindrical section to see the atomization of liquid metal. A pressure gage attached with cylindrical section provides a check on over-pressure in the atomizing chamber.

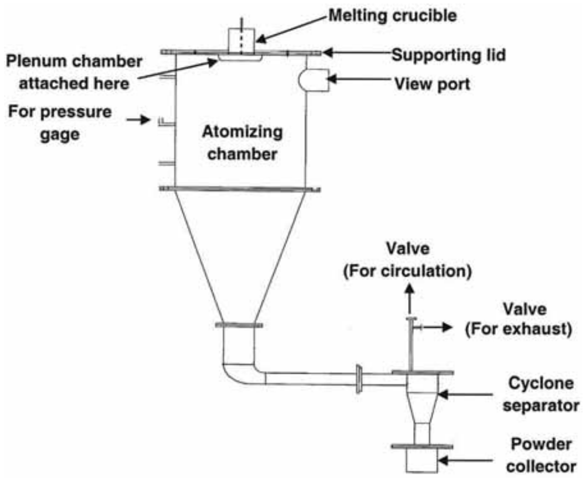

Figure 2. Schematic view of Indigenous Gas Atomizer.

3.2. *Supporting Lid*

The atomizing nozzle and plenum chamber assembly is attached to supporting lid such that when lid is placed over the cylindrical section of atomizing chamber the plenum chamber faces downwards i.e. into the chamber. Atomizing gas inlet connections for plenum chamber are also provided through the supporting lid. Atomizing gas, at desired pressure, is provided from a gas cylinder. The lid is provided with a center hole such that the center-body of plenum chamber becomes coaxial with the center hole in the lid. Figure 3 shows the schematic of assembly consisting of melting crucible, supporting lid, and plenum chamber.

3.3. *Atomizing Nozzle and Plenum Chamber*

The atomizing nozzle and plenum chamber assembly is made of stainless steel. Plenum chamber is sealed by capping a stainless steel bottom plate. Hole cut in the bottom plate allows the center-body to protrude through plenum chamber to allow teeming nozzle deliver molten metal to the atomizing nozzle tip. The bottom plate makes the nozzle arrangement confined annular convergent type. The converging angle has been kept 25^{o} with annular exit opening of 0.5 mm for gas jet. Atomizing gas emanates from the annular exit opening of atomizing nozzle to atomize the liquid metal. Figure 4 shows a schematic view of atomizing nozzle and plenum chamber.

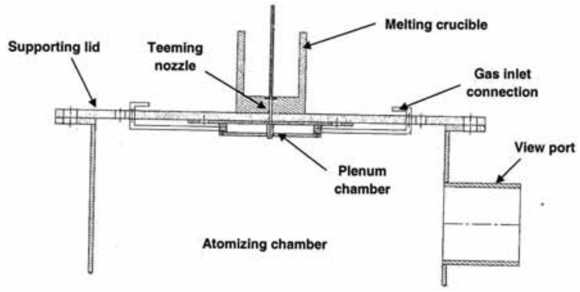

Figure 3. Schematic view of assembly consisting of melting crucible, supporting lid and plenum chamber.

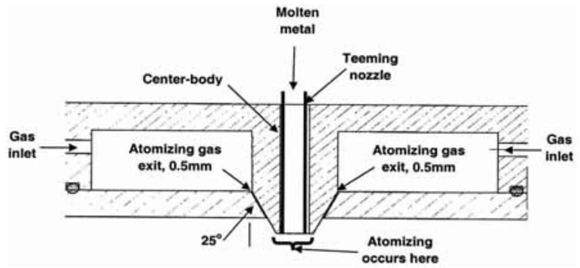

Figure 4. Schematic view of atomizing nozzle and plenum chamber.

3.4. *Melting Arrangement*

An induction generator has been employed to melt the desired metal placed in melting crucible with teeming nozzle. The crucible, with molten metal in it, sits on the lid such that the teeming nozzle is inserted into center hole in the lid and down to the tip of center-body of plenum chamber. This makes the molten metal stream to be surrounded by annular gas jet to get atomized. The batch capacity is ~ 500g of Cu. The temperature of molten metal in crucible is measured by using a K-type thermocouple.

3.5. *Powder Collection*

After atomization powder produced is transferred to cyclone separator which separates the gas and solid particles. Cyclone separator has the form of a conical section made of stainless steel. The gas alongwith powder particles enter the cyclone separator tangentially and form a cyclone inside the cyclone separator. This cyclone causes the powder particles to settle down and collect in stainless steel powder collector. The gas leaves the cyclone separator from the circulation line provided at the top of cyclone separator. The clean gas is circulated to the chamber in form of shower via connections through supporting lid. A relief valve is also provided to discharge any excess gas causing over-pressure in atomizing chamber. This adds a safety feature to the design.

4. Discussion

4.1. Key Factors and Process Variables

The melting crucible, teeming nozzle and plenum chamber assembly are the most critical components of gas atomizer. Any freezing of molten metal inside teeming nozzle depends on the design of teeming nozzle. The inner diameter of the teeming nozzle (molten metal stream diameter) should be such that it allows sufficient amount of metal to flow through it so as to provide sufficient heat to this area thus avoiding freezing of metal. Moreover, the teeming nozzle insulates molten metal and also prevents any erosion of stainless steel center-body.

The converging angle of atomizing nozzle affects the atomization behavior of the metal and thus the characteristics of the powder produced. Moreover, efficiency of atomizer to convert molten metal into powder particles rather than flakes also depends on converging angle of atomizing nozzle. Teeming and atomizing nozzles were designed keeping in view the above factors.

Smaller molten metal stream diameter and higher atomizing gas pressure produce smaller particle sizes. However, the tendency of freezing of molten metal inside teeming nozzle also increases with smaller diameter of teeming nozzle and higher pressures due to lack of sufficient heat in this area. To overcome this problem, metal has to be superheated to a sufficient degree above its melting temperature.

After getting atomized successfully, molten metal droplets solidify in-flight down towards bottom of atomizing chamber. These droplets should solidify before they strike the walls of chamber. Therefore, the size of atomizing chamber should be large enough so as to allow in-flight solidification of molten droplets. However, this size can not be too large due to placement constraints. Therefore, there should be a compromise between degree of superheating and size of atomizing chamber to ensure optimum conditions, so that metal should not freeze in the teeming nozzle and molten metal droplets should solidify before they strike the walls of atomizing chamber. Therefore, the atomizing chamber was designed such that molten metal droplets get enough time to solidify during their flight. Moreover, a series of experiments are required for obtaining an optimum degree of superheating for the desired metal.

The diameters of the exhaust line and circulation line were so selected that it created an aspiration effect at the metal exit of atomizing nozzle. This aspiration effect is necessary so as to avoid positive pressure at metal exit which can lead to dangerous ejection of melt from crucible. Moreover, this aspiration effect forces the molten metal down towards the tip of the teeming nozzle thus facilitating the atomization process.

4.2. Experimental Results

Keeping in view all of the above factors, tin (Sn) was chosen as a first metal, due to its non toxic, non pyrophoric nature and low melting temperature, to acquire some operating experience as a preliminary experiment. Sn was melted in small quantity (200 g) in a graphite crucible placed over top lid (& plenum chamber assembly) using a 25 kW induction generator. Graphite teeming nozzle was used to insulate liquid metal from stainless steel atomizing nozzle and to protect stainless steel from erosion. To avoid any premature freeze of liquid metal in teeming nozzle, it was superheated $100^{o}C$ above its melting temperature.

Once proper melting temperature was achieved, atomization was initiated by pressurizing plenum chamber and then quickly removing graphite stopper rod blocking the entrance of liquid to teeming nozzle at bottom of crucible. This is followed by suction of molten metal into the teeming nozzle due to aspiration effect and formation of molten metal droplets. These droplets appear as upside down conical luminous jet near the atomizing nozzle. After various attempts and slight modifications in operational parameters, tin was atomized successfully. The operating parameters and particle sizes obtained are given in Tables 1 and 2 respectively.

After gaining confidence and establishing the atomizing process, higher melting point metal, copper (Cu), was atomized. Copper was atomized at five different atomizing pressures of Ar gas. The operating parameters and particles sizes obtained are given in Tables 3 and 4 respectively.

Table 1. Operating parameters and conditions used in gas atomization of tin.

Parameter	Condition
Melting Temperature	~232^oC
Degree of Super Heat	~100^oC
Atomizing Media	Argon
Atomizing Nozzle Type	Converging angle = 25^o Gas exit gap = 0.5 mm
Diameter of Teeming Nozzle	3 mm

Table 2. Particle sizes of tin powder produced at different atomizing gas pressures.

Atomizing Gas Pressure (bar)	Particle Size Range (µm)	Average Particle Size (µm)
8	80-150	100

Table 3. Operating parameters and conditions used in gas atomization of copper.

Parameter	Condition
Melting Temperature	~1083^oC
Degree of Super Heat	~200^oC
Atomizing Media	Argon
Atomizing Nozzle Type	Converging angle = 25^o Gas exit gap = 0.5 mm
Diameter of Teeming Nozzle	3 mm

Figure 5 shows effect of variation in atomizing gas pressure on particle size of powder produced. It is clear from the figure that with the increase in atomizing gas pressure particle size of powder produce decreases. This is due to the fact that with increase in pressure the atomizing gas annular jet strikes the molten metal stream with greater impact velocity thus disintegrating the molten metal stream into finer droplets which solidify as powder particles.

Table 4. Particle sizes of copper powder produced at different atomizing gas pressures.

Atomizing Gas Pressure (bar)	Particle Size Range (µm)	Average Particle Size (µm)
2	165-750	350
3	140-700	300
5	50-340	117
8	30-190	85
10	20-110	51

Figures 6a and 6b show optical micrograph of powder particles of copper atomized at 2 and 10 bar atomizing gas pressure respectively. It is clear from the micrographs that the powder particles are spherical in shape.

In both of these series of experiments, powder produced was efficiently collected in the powder collection port. Moreover, view port provided a good view of the atomization process. A certain quantity of metal transforms into flakes which get stick with inner walls of atomizing chamber. Therefore, between runs with different metals cleaning of atomizer is required.

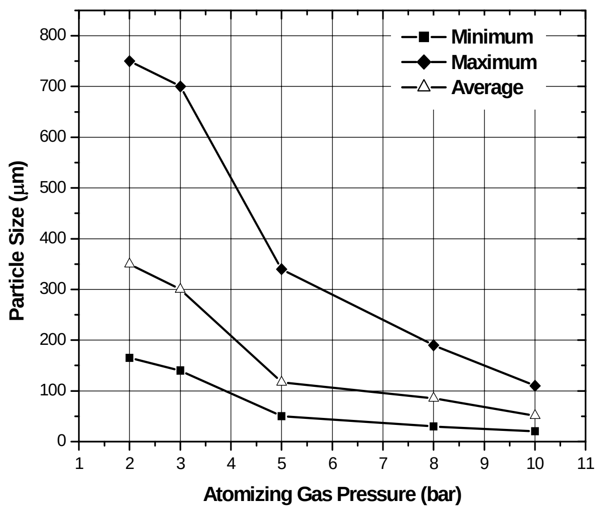

Figure 5. Variation in particles sizes with atomizing gas pressure.

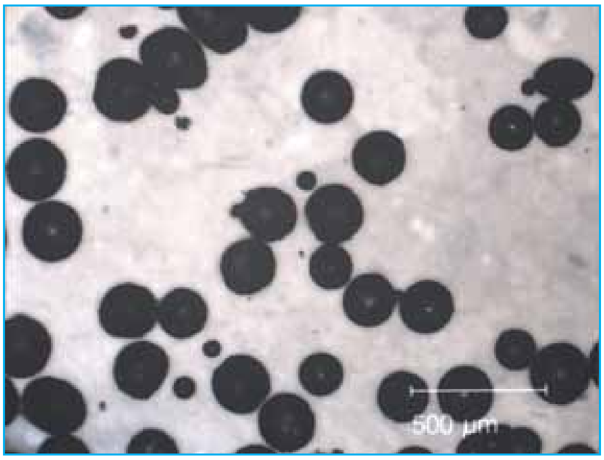

Figure 6a. Optical micrograph of Cu powder particles produced at 2 bar of atomizing gas pressure.

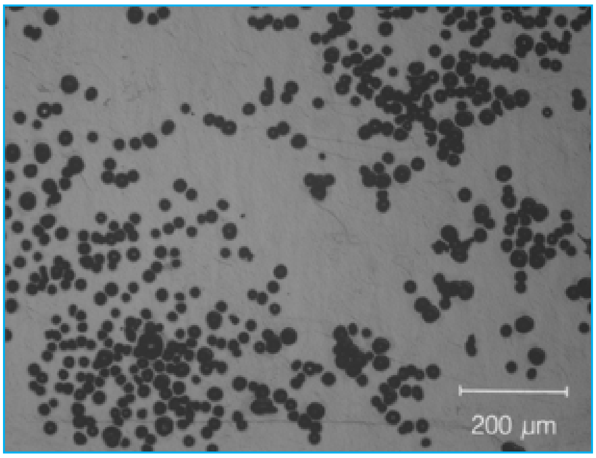

Figure 6b. Optical micrograph of Cu powder particles produced at 10 bar of atomizing gas pressure.

5. Conclusions

i. An indigenous laboratory scale gas atomizer was designed, fabricated and operated successfully.

ii. A number of key factors and parameters were optimized for a successful atomization process. These include size of atomizing chamber, degree of superheating of metal above its melting temperature, diameter of molten metal stream, geometry of atomizing nozzle, and atomizing gas pressure.

iii. Tin and copper were atomized successfully and collected efficiently in powder collector.

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