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Design and Construction of Water Atomizer for Making Metal Powder

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Abstract

Water Atomization for metal powder is an appropriate method for producing metal powder from different kinds of metal. Typically, a water atomizing machine is designed with a molten metal spraying chamber in a vertical or horizontal orientation depending on a nozzle design, a molten metal spraying chamber and related components. The main variables influencing the working condition of the water atomization process, which affect sizes, shapes and distribution of metal powder particles, are water pressure, water flow rate, a temperature higher than melting point of liquid metal and flow rate of liquid metal. The water atomizing machine in the study was designed and constructed in which the variable values mentioned could be adjusted. The metal powder produced with the water atomizing machine was from copper, low carbon steel and AISI 304-stainless steel. The result indicates that the water atomizing machine was able to produce the intended metal powders from different kinds of metal. These are the metal powders with a smaller size than 105 micron, with not less than 90% of liquid metal per each experiment, and with irregular shapes.

Key words: Water Atomization, Metal powder

Introduction

Powder metallurgy or P/M is a process of powder fabrication, powder characterization and different kinds of metal powder shaping. The produced materials will be used as engineering parts. In addition, the P/M process is superior to other processes in that:

1. a workpiece has a mechanical compacting property and no problem of component distribution.
2. the P/M process yields high production, low loss of volume and low cost per unit.
3. it is an alternative process for difficult material forming and transforming such as metal or alloy with high heat resistance and compound materials.
4. it is a process which produces novel materials and high performance materials.

Metal powders are also used as raw materials in thermal spray to better strengthen the workpiece surface against abrasion, dye catalyst, toner ingredients and explosive components. Currently, the engineering production has developed different methods and production processes to produce better quality workpieces, reduce material scraps, to serve a market supply and lower the cost per workpiece. Metal powder, therefore, is a preferable material in the production process. More metal powder is used in various kinds of industry such as automobile, electronic equipment, mobile phones, and sport equipment including different kinds of hardware. Consequently, metal powder is considered one of the most important raw materials for part production in industry [(1)]. It can be mentioned that metal powder produced as raw materials for M/P production process is crucial. As of 2010 in Thailand, more metal powder is utilized in engineering component production, and consequently an increasingly higher quantity of metal powder is produced. However, the largest proportion of metal powder as raw materials is imported, which is a limit directly affecting the industrial development. Moreover, the domestic industry that needs metal powder as raw materials for fabricating engineering parts in automobiles, electrical and electronic equipment, is gradually increased. The methods in producing different kinds of metal powder as raw materials for the industry differ depending on a special property of each metal. Typically, there are three methods of metal powder production: atomization, chemical and physical. Each method can be subdivided depending on a special property of metals. An atomization process for metal powder is a complicated, but effective one. It is also used to produce metal powder from different types of metal. The principle of atomization

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process is to make molten metals/alloys or melts to become droplets or particles, which are cooled to become metal powders in different sizes and shapes. Much force with different methods is needed to turn the molten metals/alloys or melts into particles.

The metal powered product by water atomization is in better compact forms, but possesses less density than that of gas atomization due to different shapes and particles of powder. Water pressure of spraying is believed to be most effective in terms of sizes of metal particles. German reported the result of his experiment stating that the water pressure spraying of 1.7 MPa could produce an average size of 117 μm particles, but with an average size of 42 μm particles when 13.8 MPa of water pressure spraying was applied. In other words, when a smaller size of the particles is needed, a higher water pressure of spraying is to be applied. For example, a size of 10 of μm particles needs water pressure of spraying of 70 MPa, which is called High-Pressure Water Atomization (HPWA). The same report also indicated that the adjustment of V-jet nozzle could produce smaller particles than that of a Cone nozzle applying the same values of water pressure spraying.

Seki et al. [4] propose the High-Pressure Water Atomization (HPWA) process in which a water pressure of up to 70 MPa was applied. In the report, the powder metals with an average size smaller than 10 μm are presented below, as well as two equation formulas for predicting the average size of metal particles produced by high water pressured nozzle:

$$D = 68P^{-0.056} \quad \text{for V-jet Nozzle} \ldots\ldots (1)$$
$$D = 114P^{-0.058} \quad \text{for Cone Nozzle} \ldots\ldots (2)$$

where D is average size of metal particle (μm) and P is water pressure (MPa).

In the study, water atomization process was selected because it was considered an appropriate and effective method, in particular for metals with a melting point over 1,000°C and irregular forms. The objectives of design and constructing a water atomizing machine for metal powder are:

- to design and construct a water atomizing machine for metal powder
- to examine the variables affecting the produced metal powders by the water atomizing machine for metal powder
- to provide a guideline for design and construction development for further practical use in the related industry.

Materials and Experimental Procedures

The experiment was to invent a water atomizing machine for producing metal powder by means of high pressured water current sprayed to collide with the vertical flowing molten metal to form different demanded sizes of metal particles. The designed and constructed machine is composed of the main parts as shown in Figures 1 and 2:

(1) Rectangle-shaped spraying chamber used to collect powdered metal.

(2) Spraying chamber base with inverted pyramid of 45° and 30° slopes used to drain powdered metal to the spraying chamber.

(3) Closing-opening outlet of molten metal spraying chamber for collecting powder metal.

(4) Two safety glass channels for observing the spraying conditions.

(5) Top lid with trapezoid shaped dome for nozzle and screen installation for checking the working conditions as in Figure 3.

(6) Top lid with trapezoid shaped dome for sucking fan installation where the heated vapours were collected and released out to reduce the pressure in the spraying chamber.

(7) Vapour Ventilating Fan used to suck the vapours out of the spraying chamber to the Vapour Sucking Cyclone as in (8).

(8) Vapour Sucking Cyclone used to capture vapours and metal particle.

(9) Vertical molten feeding Tundish to collect and feed the molten metal collected from the Tundish.

(10) Tundish Base for supplying molten metal (9) and a base for spraying nozzles (12) and (13).

(11) Pipe supplying molten metal vertically and flow quantity Control by adjusting 3 different sizes of pipe diameters: 5 mm, 6 mm and 7 mm.

(12) Two sets of high water pressure with V-jet Spraying Nozzles, each set containing 2 nozzles. Nozzle Set 1 is a main nozzle spraying high pressured water to split the molten metal from the Tundish (9); Nozzle Set 2 is a lower extra nozzle horizontally spraying water against the vertical water sprayed by Nozzle Set 1 to accelerate the cooling rate. Each nozzle is designed to enable ranges and nozzle adjustment in 3 levels of axis.

(13) Cone Spraying Nozzle, which is designed to enable the adjustment of a conical apex between 45-90° by choosing the Set of nozzles in Figures 4 and 5.

(14) High Pressured Pump designed for 4 water pressured pumps up to 280 bar, flow rate at 20 liters/min. The pumps are in parallel circuit and are separately and independently controlled.

(15) Tank with safety valve and proof explosion equipment. The tank is ready for water pressure measuring equipment.

(16) Pump for sucking and supplying raw water into a filter system.

(17) Set for filtering raw water and water supply system to high pressured pump.

(18) Valve system supplying high pressured water to high pressured V-jet nozzles (12), each equipped with separately adjustable valves for flowing quantity and water pressure.

(19) Valve system supplying high pressured water to high pressured Cone nozzles (13).

(20) Chamber controlling the function of pumps and sucking fans.

(21) Handle for closing and opening the base of molten metal spraying chamber.

(22) Equipment for protecting high pressured accumulator from explosion (15).

(23) Safety valves of high pressured accumulator (15).

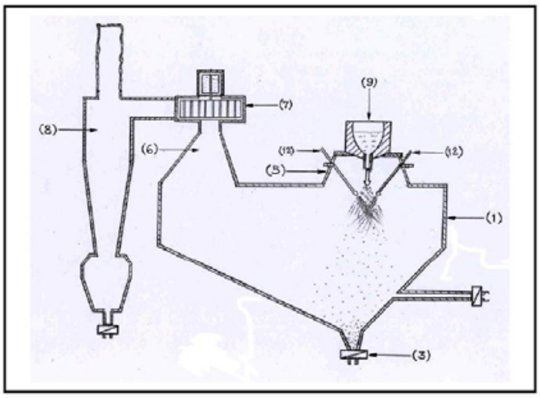

Figure 1. Internal Description of a Water Atomizing Machine.

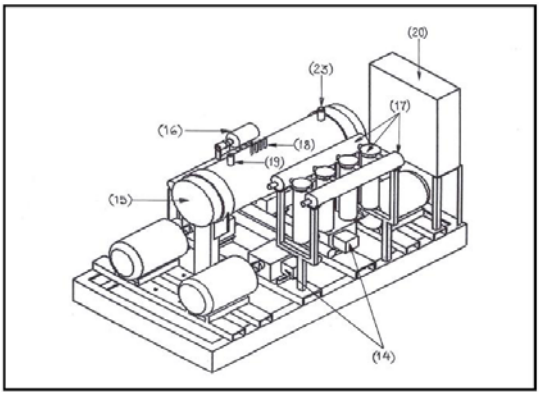

Figure 2. Full Set of High Water Pressured Pump with 280 bar and Flow Rate at 80 liters/min.

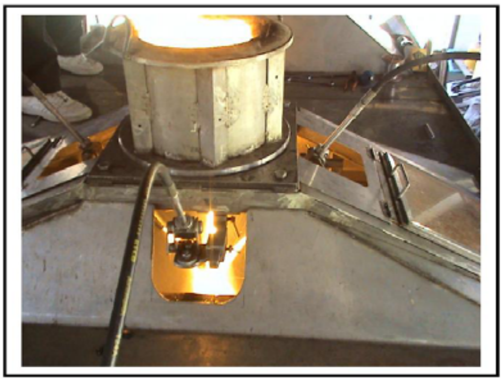

Figure 3. Molten Metal Spraying by V-jet Nozzle.

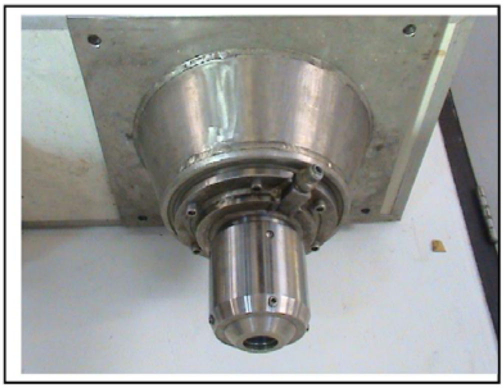

Figure 4. Inverted Cone Shaped Nozzle.

Figure 5. Changeable Cone Nozzles.

Figure 6. High Pressure Water Pump.

Table 1 shows a set of machine and assembled parts with components used to adjust the desired experiment variables. The machine was adjusted to use with 3 different variables: copper, low carbon steel and AISI 304 stainless steel in different conditions to find the best products of powdered metals.

Table 1. Controlled Variable Values Set as Equipment Efficiency.

Control Variable	Value	Unit
Water pressure (P)	$P_1 = 240$ $P_2 = 260$ $P_3 = 280$	bar
Superheat temperature (T)	$T_1 = 90$ $T_2 = 120$ $T_3 = 150$	°C
Melt orifice diameter (d)	$d_1 = 5$ $d_2 = 6$ $d_3 = 7$	mm

Note: 1. A -Ø 5 mm. nozzle yields the lowest flow rate of molten metal.
2. A -Ø 6 mm. nozzle yields the most moderate flow rate of molten metal.
3. A -Ø 7 mm. nozzle yields the highest t flow of molten metal.

Results and Discussion

The result of metal powder production indicated that the adjustment of all experiment variables affected the efficiency of the Water Atomizing Machine in producing 3 kinds of powdered metal. The results of using V-jet nozzles and converted cone nozzles are concluded as follows: The application of the nozzles with Ø 5 mm and Ø 7 mm, super heat temperature lower than 150°C and a minimum water pressure at 240 bar produced metal powders smaller than 105 micron yielding less than 70% of molten metal input. However, the application of the nozzle with Ø 5 mm and minimum superheat temperature at 90°C could not let all molten flow from the tundish. Some hardened portion was stuck in the tundish. (The tundish was preheated at 800°C.) This happened because a lower flow rate of molten metal reduced a level of superheat temperature of molten metal resulting in an increased viscosity. The application of the nozzle with Ø 7 mm, a maximum flow rate of molten metal, superheat temperature at 90°C and minimum water pressure at 240 bar shows that water quantity and water pressure compared to the quantity of molten metal was at a small quantity of 1:4. As such a certain proportion of molten metal crashed by water pressure was split into bulky grains and vapours bigger than 105 micron. In other words, the metal powders smaller than 105 micron, were produced in a small quantity. Besides, a flow rate of molten metal higher than that of water pressure could slow down the cooling rate of metal particles resulting in a smaller quantity of irregular shapes of metal powder. The application of the nozzle with Ø 6 mm, a maximum flow rate of molten metal, superheat temperature at 150°C and minimum water pressure at 280 bar produced the best experiment result by the Water Atomizing Machine when used with the three kinds of metal in this experiment as shown in Table 2, Figures 7, 8 and 9.

Table 2. The experiment result using a V-Jet Nozzle producing –105 micron powder metal.

Types of Metal	Quantity of Molten Metal (kg)	Water Pressure (bar)	Super-heat Temp. (°C)	Quantity of Powdered Metal obtained by					
				∅ 5 mm Nozzle		∅ 6 mm Nozzle		∅ 7 mm Nozzle	
				kg	% yield	kg	% yield	kg	% yield
Low-carbon steel	10	240	150	6.885	68.85	7.735	77.35	7.420	74.20
		260		7.585	75.85	8.160	81.60	7.620	76.20
		280		8.125	81.25	9.220	92.20	8.535	85.35
AISI-304 stainless steel	10	240	150	6.235	62.35	6.735	67.35	7.020	70.20
		260		7.825	78.25	8.055	80.55	8.235	82.35
		280		8.215	82.15	9.015	90.15	8.420	84.20
Copper	10	240	150	7.020	70.20	7.450	74.50	7.210	72.10
		260		7,720	77.20	8,345	83.45	7,820	78.20
		280		8,625	86.25	9,330	93.30	8,725	87.25

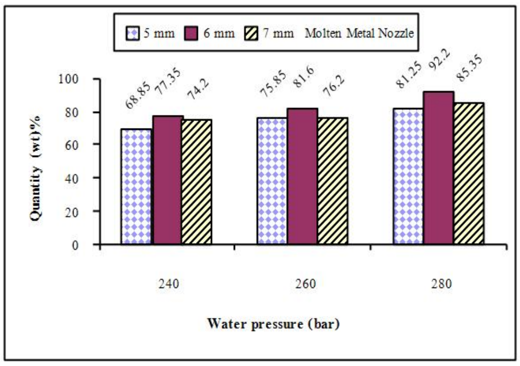

Figure 7. Yield quantity (%wt) of low carbon steel powder obtained from 10 kg of raw metal.

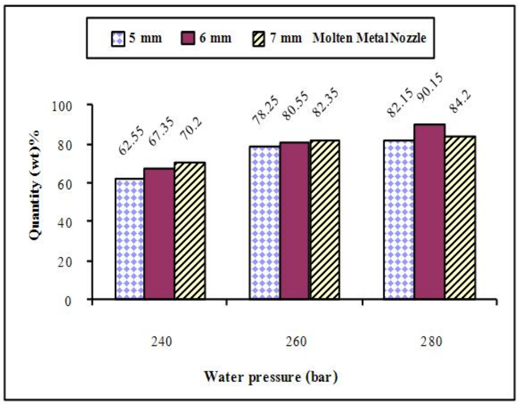

Figure 8. Yield quantity (%wt) of AISI 304 stainless steel powder obtained from 10 kg of raw metal.

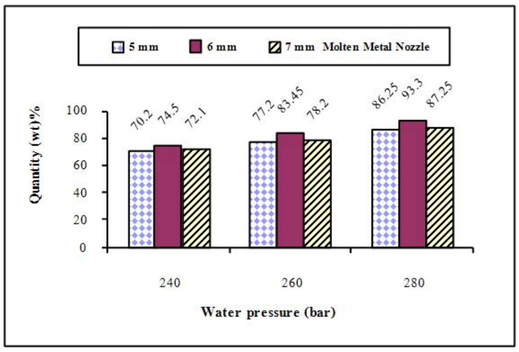

Figure 9. Yield quantity (%wt) of Copper powder obtained from 10 kg of raw metal.

However, when 90°C and 120°C superheat temperatures were applied, the produced metal powders were widely distributed. In particular, the average size of metal powders (d_{50}) was bigger when applied to variables of reduced water pressure. This occurred at all levels of molten flow rate, the result of which is shown in Table 3. The result of the same variables applied to an inverted cone nozzle was not good when compared to that of a V-Jet nozzle. One of the main factors was a combined flow rate of water pump which was limited at 80 liters/min, and which caused a considerable reduction of water pressure at a nozzle when spayed through a cone nozzle. This occurred due to a much more increased total area of annular ring which caused a reduction of water pressure and water speed. The molten flow rate in the experiment was 13-15 kg/min depending on the type of metal; and the total water flow rate was 80 liters/min.

Table 3. Yield ratio (%wt) of metal powders produced from Low-carbon steel, AISI-304 stainless steel and Cu with controlled variables-Molten flow rate distributed by Ø 5 mm, 6 mm and 7 mm at maximum water pressure at 280 bar at 3 levels of superheat of metals.

Types of metal	Quantity of Molten Metal (kg)	Water Pressure (bar)	Ø of metal flow (mm)	Yield ratio (%wt) of metal powder obtained from various superheat Temp.		
				90°C	120°C	150°C
Low-carbon steel	10	280	5	68.30	72.10	81.25
			6	76.80	78.70	92.20
			7	77.20	81.85	85.35
AISI-304 stainless steel	10	280	5	53.80	62.50	79.15
			6	62.40	71.35	90.15
			7	65.40	73.85	84.20
Copper	10	280	5	64.60	69.95	86.25
			6	68.60	71.50	93.30
			7	70.40	73.25	87.25

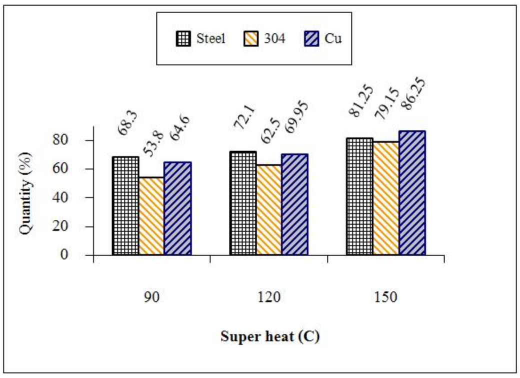

Figure 10. Powder Yield Quantity from ∅5 mm Nozzle.

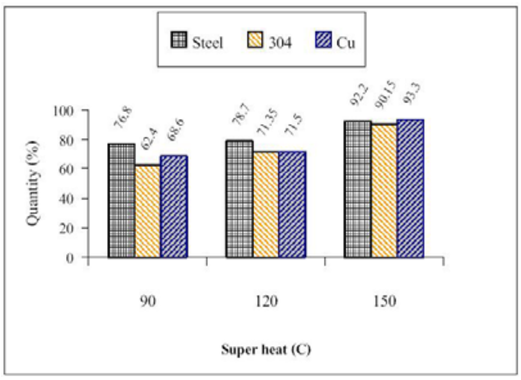

Figure 11. Powder Yield Quantity from ∅6 mm Nozzle.

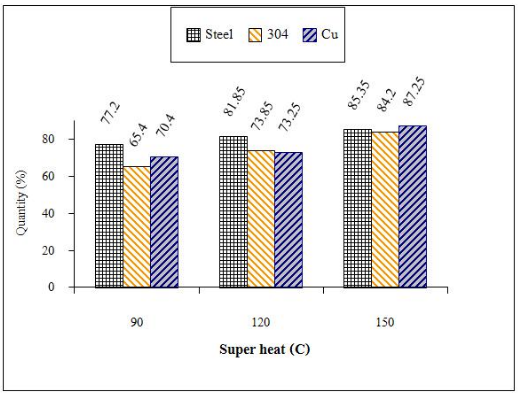

Figure 12. Powder Yield Quantity from ∅7 mm Nozzle.

From a given equation $D = 68P^{-0.056}$ spraying by V-jet Nozzle

where D is an average size of metal powder (μm) and P represents water pressure. The designed Water Atomizing Machine in the study can be applied to a maximum water pressure of 280 bar or 28 MPa represented in Equation 1 as shown below.

$$D = 68(28)^{-0.056} = 56.42\ \mu m$$

The value from Equation 1 is 56.42 or approximately 56 μm. When the value is compared to the average size of metal particles produced by the Water Atomizing Machine in this study by applying the working control condition as set in Table 1, the result coincides with that of the HPWA process. Although its water pressure is 50% less than that of HPWA, the average sizes of particles produced from the three types of metal were close to that of the predicted one in Equation 1. The results are shown in Table 4. Sieve analysis with standard of ASTM E 11 [1] was employed to calculate average sizes of metal particles (d_{50}).

Table 4. Average sizes (d_{50}) of particles produced from controlled superheat at 150 °C, 280-bar water pressure and liquid metal flow diameter by 3 sizes of Ø 5, 6 and 7 mm nozzles.

Metal Types	(d_{50}) from standard sieve analysis (μm)			(d 50) from calculation (μm)
	∅5 mm	∅6 mm	∅7 mm	56
Low-carbon steel	61	58	68	
AISI 304 stainless steel	79	60	72	
Copper	65	54	62	

Conclusions

1. The ratio of flow rate of liquid metal and total flow rate of high water pressure used should not be less than 1:4. In order to obtain metal powders with irregular forms, the ratio must be 1:5.7.

2. High heat temperature level of liquid metal, flow rate of liquid metal and water pressure directly affected average sizes (d_{50}) of produced particles. The best parameter of this water atomizing machine is high heat temperature at 150°C, liquid metal flow rate from Ø 6 mm nozzle (13-15 kg/m depending on a metal type) and 280-bar water pressure with total flow rate at 80 liters/min. The water atomizing machine could produce the metal powder from the three types of metals with an average particle size of 56 μm with irregular particle forms.

3. According to 1 and 2 above, the experiment must be undertaken under a strict condition. That is the ratio of the impact of high pressure water and liquid metal flow (d_m: W: (L/sin γ) equals 1: (5.5 to 6.5) : (25 to 35) as shown in Figure 13.

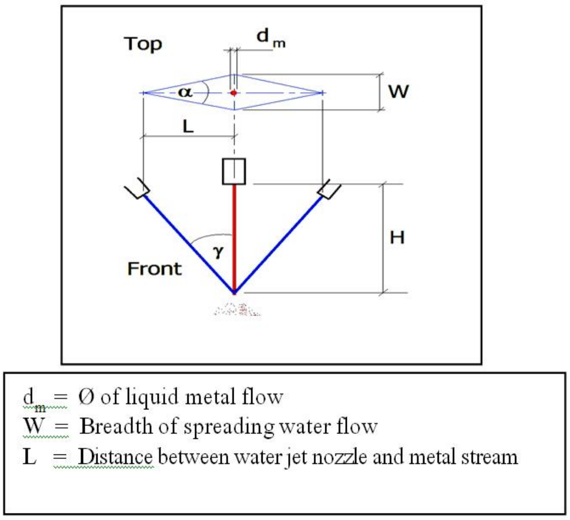

Figure 13. Configuration of main water jet nozzle.

4. The result of the same variables applied to a cone nozzle was not good resulting from the water pressure at a crashing point with molten metal flow considerably reduced (only comparable with equal high water pressure pumps). This occurred due to the fact that the total area of annular ring is larger than the combined one of the 4 V-jet nozzles. Consequently, the metal powders obtained have an average size larger than 105 μm and in a high quantity.

5. The Dome-shaped lid (6), sucking fan (7), and Cyclone affected the efficiency of metal powders directly and positively by preventing the molten metal and water vapours from spattering back during the experiment.

References

1. ASM (1984). *ASM metals handbook volume 7 powder metallurgy*. Ohio, OH: ASM International.

2. German, R.M. (1984). *Powder metallurgy science*. Princeton, NJ: Metal Powder Industries Federation: 80.

3. Tongsri, R. (2001). Powder metallurgy part 2. *PM Tech*. **2**: 2-4.

4. Seki, Y., Okamoto, S., Takisawa, H. & Kawai, N. (1990). Effect of atomization variables on powder characteristics in the high-pressured water atomization process. *Metal Powder Report* **45(1)**: 38-40.