Experimental Optimization of Gas Atomization for Additive Manufacturing

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Contents

1 Factors influencing metallic powder size and quality during gas atomization for metal 3D printing

During **gas atomization** used to produce metallic powders for **metal additive manufacturing** (Laser Powder Bed Fusion (LPBF), Electron Beam Melting (EBM), and Directed Energy Deposition (DED)), the **particle size** and **powder quality** (sphericity, cleanliness, particle size distribution, internal porosity) are directly influenced by several key factors. These factors can be grouped into *melt properties*, *process parameters*, and *environmental conditions* [1, 2, 3].

1.1 Properties of the molten metal

- Lower viscosity → easier jet breakup → finer particles [4, 3]
- High surface tension → larger droplets [4]
- Higher density → more energy needed to fragment (generally produce coarser powder) [3]
- Alloying elements affect viscosity and surface tension. Oxides and inclusions → sphericity degradation and satellite formation [5, 6].

1.2 Gas atomization process parameters

- Higher gas pressure/velocity → finer particles [3, 5]
  /!\ Excessive values → satellites and irregular particles [5]
- **Helium**: very fine particles (low density, high velocity) [1, 6]
- **Argon**: good quality (but cost compromise) [2]
- **Nitrogen**: economical but reactive with some alloys (Ti, Al) [2]
- High gaz-to-metal massflow ratio → improve fragmentation [7]
  /!\ Excessive values → jet instability and broader particle size distrubition [7]
- **Hydrogen** (less common due to high risk of explosion): Very low molecular weight → high gas velocity → finer powder [1]
  /!\ Soluble gases → internal porosity [6]

1.3 Nozzle geometry

The nozzle design (gas jet angle, symmetry, gas-metal interaction distance) → affects particle size, sphericity, and powder yield [5, 3].

1.4 Thermal conditions

- Higher superheat → lowers viscosity and improves atomization → finer and more spherical particles. Excessive values → evaporation of alloying elements, oxidation [3, 2]
- Rapid solidification → spherical particles and fine microstructure. Slow cooling → deformed particles and satellite [6, 5]
  /!\ high cooling rates → increase interal porosity [6]

1.5 Atomization environment

- Oxygen and moisture → surface oxidation, reducing flowability, wettability, and laser absorptivity [2, 8]
- reduces chamber pressure → improves fragmentation [3]
  /!\ High pressure increases droplet collisions and agglomeration [5]

1.6 Summary of key influencing factors

Factor	Particle Size	Powder Quality
Gas pressure / velocity	Very high	High [3]
Gas type	High	Very high [1]
Superheat temperature	High	High [2]
Nozzle geometry	Very high	Very high [5]
Atmosphere purity	Low	Very high [8]
Metal properties	High	High [4]

2 Powder quality caracterization

2.1 ... of the particles, independantly

- Size
- Geometry (sphericity, satellite...)
- Porosity
- what else?

2.2 ... of the powder = behavior of the particles between each other

- **Apparent density**: Mass of powder per unit volume in a loose, non-compacted state, including inter-particle voids.
- **Tap density**: Density of a powder after mechanical tapping or vibration, allowing particle rearrangement and packing.
- **Compressibility**: Ability of a powder to decrease in volume under applied pressure.
- **Flow properties**: Ability of a powder to flow consistently and uniformly under gravity or external forces.
- **Green strength**: Mechanical strength of a compacted powder body before sintering.
- What else?

3 Powder quality impact on printed parts

3.1 Optimized powder parameters for LPBF

LPBF (Laser Powder Bed Fusion) imposes strict requirements on powder characteristics to ensure stable recoating, uniform melting, and defect-free parts [8, 2].

- Particle size distribution (PSD): **15–45 μm** (typical) [8]
- $D_{10}/D_{50}/D_{90}$: narrow distribution preferred [2]
- Sphericity: > 0.95 [5]
- Apparent density: $> 50\%$ of theoretical density [8]
- Hall flow rate: < 25 s / 50 g [8]
- Oxygen content:
  - Ti alloys: < 0.15 wt.% [2]
  - Al alloys: < 0.10 wt.% [2]
  - Steels/Ni alloys: < 0.05 wt.% [2]

3.2 Typical powder defects and their impact on LPBF

- Satellite = droplet collision → poor powder flowability; irregular speading, increase porosity in printed part [5]
- Internal porosity (rapid solidification) → porisity transferted to printed part and reduce fatigue strength [6]
- Wide Particle Size Distribution → Segregation during recoating, non-uniform melting behavior, surface roughness variation [8]

3.3 Powder quality-process-property relationship

Powder Attribute	Part Properties
High sphericity	High density, smooth surface [5]
Low oxygen content	Improved ductility and fatigue [2]
Low internal porosity	High fatigue and fracture resistance [6]
Narrow PSD	Dimensional accuracy [8]
Good flowability	Reproducibility [8]

4 To dig

4.1 Powder manifactoring processes

gas atomization, water atomization, centrifugal atomization, plasma atomization, mechanical attrition and alloying, melt spinning, rotating electrode process (REP), and a variety of chemical processes. (see ref [5] "Leo VM Antony, Ramana G. Reddy, Processes for production of high-purity metal powders, JOM 55 (3) (2003) 14-18." in the paper [1])

4.2 Measurment methods

For:

- Size
- Geometry (sphericity, satellite)
- Porosity
- Apparent/Tap density, compressibility
- Flow properties
- Oxygen content
- ...

4.3 Coarsening

Coarsening in metallurgy is a **thermally activated microstructural evolution** that occurs when a metal or alloy is exposed to **elevated temperature for a sufficient time**.

In gas atomization of metal powders, classical coarsening is generally negligible due to extremely high cooling rates and short solidification times; it may only occur in large particles or during post-atomization thermal treatments.

4.4 Liquidus / Superheat / Overheating

Overheating brings oxidation even in inert gaz?

5 To read

- Atomization processes of metal powders for 3D printing, Kassym, Kazybek and Perveen, Asma [1]
- Metal powder atomization preparation, modification, and reuse for additive manufacturing, Ren, P. and others [2]
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- Investigation on the effect of the gas-to-metal ratio on powder properties and PBF-LB/M processability, Cacace, S. and others [7]
- Gas atomization of duplex stainless steel powder for laser additive manufacturing, Cui, C. and others [9]
- A review on metal powders in additive manufacturing, Saheb, S. H. and others [8]
- Review of gas atomisation and spray forming phenomenology, Zhang, R. and Zhang, Z. and Liu, Q., [3]

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- Gas atomization of metals, Uhlenwinkel, V. [6]
- Numerical analysis of droplet breakup, cooling, and solidification during gas atomisation, Wang, Gezhou and Deng, Yuanbin and Adjei-Kyeremeh, Frank and Zhang, Jiali and Raffeis, Iris and Buhrig-Polaczek, Andreas and Kaletsch, Anke and Broeckmann, Christoph, [10]
- Pre-breakup mechanism of free-fall nozzle in electrode induction melting gas atomization, Zou, Haiping and Xiao, Zhiyu, [11]
- Numerical simulation study on cooling of metal droplet in atomizing gas, Zhang, Min and Zhang, Zhaoming, [12]
- Effects of different nozzle materials on atomization results via CFD simulation, Li, Xiangyu and Du, Jianjun and Wang, Licheng and Fan, Jiangli and Peng, Xiaojun [13]

6 QUESTIONS

1. Each parameter might vary depending the metal material and the choosen inert gaz. In this PhD, do we want to optimize a specific material in a specific environement (at least as a stating point)? If yes, which ones?
2. Plasma atomization produces higher-quality powders than gas atomization but comes at a high cost. Is one of the goals of this PhD to challenge plasma atomization by developing a cheaper alternative?

Criterion	**Gaz atomization**	**Plasma atomization**
Production cost	Moderate	High
Particule sphericity	High	Very high
PSD	Wide range (5-200 µm)	Narrow range (10-60 µm)
Satellite	Possible	Very rare
Internal porosity	Possible	Very rare
Material flexibility	Broad (steel, Al, Ni, Co)	Mainly Ti, Ni, reactive alloy

Table 1: This is the table 1

3. During this PhD, the student has to teach during few hours or it is not mandatory?

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