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High-speed cinematography of gas-metal atomization

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Abstract

A high-speed cinematographic footage of a 304L stainless steel gas atomization, recorded at the National Institute of Standard and Technology (NIST), was analyzed using a discrete Fourier transform (DFT) algorithm. The analysis showed the gas atomization process possesses two prominent frequency ranges of melt oscillation (pulsation). A low-frequency oscillation in the melt flow occurring between 5.41 and 123 Hz, with a dominant frequency at 9.93 Hz, was seen in the recirculation zone adjacent to the melt orifice. A high-frequency melt oscillation range was observed above 123 Hz, and was more prominent one melt-tip-diameter downstream in the melt atomization image than upstream near the melt tip. This high-frequency range may reflect the melt atomization frequency used to produce finely atomized powder. This range also included a prominent high frequency at 1273 Hz, which dominated in the image further away downstream from the melt tip. This discrete high-frequency oscillation is most probably caused by the aeroacoustic "screech" phenomenon, intrasound (<20 kHz), a result of the atomizing gas jets undergoing flow resonance. It is hypothesized that this discrete intrinsic aeroacoustic tone may enhance melt breakup in the atomization process with evidence of this fact in the melt images.

Keywords: Gas atomization; Discrete Fourier transform; Melt flow oscillation; Aeroacoustically enhanced atomization

1. Introduction

The production of metal powder using high-pressure gas atomization technique (generally >3 MPa) is a widely used process for the powder metallurgy industry for manufacturing a wide range of spherical metal powder alloys. Given the fact that the metal powder properties generally improve with smaller powder particle size, close-coupled atomizers are of great interest and controlling their performance parameters is critical for the metal powder producing industries. The close-coupled gas atomization technique is however considered to be more of an art than a science, and is not readily understood. This circumstance is a result of several issues. Firstly, the atomization nozzle design is considered a proprietary technology for each company or the "workhorse" of any powder production facility, and is therefore not available for public analysis and review for technical merits. Secondly, the onsite development of atomizer design is difficult due to the plant operations' inherent variability that would naturally hamper the atomizer development process. Lastly, an investment for research and development is costly and therefore often lacking in most powder producing industries even though the return on investment, strongly dependent on the atomizer technology, exists. Under these premises, understanding of the operational characteristics of close-coupled gas atomizers has been slow to progress in the metal powder producing industries.

It seems reasonable to assume that in the atomization process of molten metal, a dynamic balance exists between the strong aerodynamic forces of the supersonic atomization gas and the high momentum and heat content of the melt flow, which is likely to produce a melt oscillation effect. Literature on this common observed melt oscillation phenomenon is absent however. This research work uses a high-speed film footage recorded by the Atomization Consortium (es-

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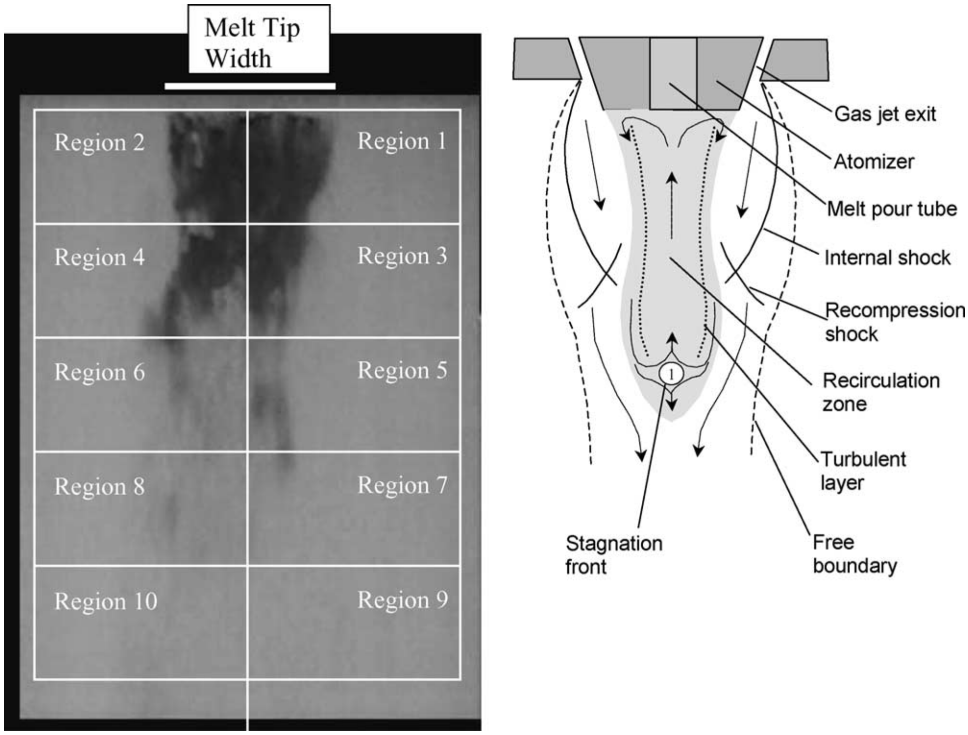

Fig. 1. A frame of the high-speed cinematographic recording of the atomization process at NIST. Each frame is divided into 10 sub-images as shown. The actual atomization process is vertically downward. A schematic depiction of the atomization recirculation zone (shown in open-wake condition) is presented adjacent to the recording (reproduced with modification from [4]).

tablished between 1984 and 1986) at the National Institute of Standard and Technology (NIST), and is used herein to study the melt oscillation frequency commonly observed in the gas-metal atomization process.

2. High-speed cinematography

A high-speed film footage (10,000 frames per second with 0.04 ms shutter speed) recorded by NIST on a supersonic inert gas-metal atomizer (SIGMA) was analyzed. The SIGMA is a high pressure gas atomizer type (HPGA-type) atomizer. The melt atomization footage was of a 304L stainless steel alloy atomized at 6.5 MPa, using argon gas. The melt was gas-atomized downwards into the atomization chamber. The atomization pressure was sufficient to create closed-wake atomizing operation conditions [1]. The SIGMA atomizer body consists of 18 convergent jets located about a melt pour tube of 9.5 mm diameter, with a melt orifice of 2.5 mm. Details of the atomization process can be found in other articles [1,2].

3. Image processing

The high-speed cinematography recording of the melt atomization was transferred from a 16 mm film onto a Super VHS tape via an analog process. Approximately 11,055 frames from the Super VHS tape were digitized to a resolution of 480 × 640 pixels, and the area coverage of the melt was examined for individual image frames. The analysis of the melt flow in the atomization footage was made from a two-dimensional picture of a three-dimensional melt image.

Each frame was divided into ten regions along the length of the atomization plume (Fig. 1). In each region, a different image threshold value, on a 255 gray scale, was chosen according to its ability to distinguish the melt from the gray background. In most cases, the gray scale transitioned rapidly from the light background to the dark melt. The threshold value was selected to match the most rapid gray scale transition. Away from the melt tip, the melt progressively became lighter as it was being atomized into fine droplets that became too small for detection. Therefore, the fixed threshold value was determined separately for each of the 10 regions. An image processing software (Irfan View©) was then used to measure the area density of the melt obtained by summing pixels above the threshold in each of the 10 regions. The melt density for an entire image was computed by the summing the 10 regions.

To quantitatively analyze for the presence of any dominant breakup frequency during the gas-melt atomization process, a discrete Fourier transform (DFT) was subsequently applied to each of the 10 regions, then to the entire image (the sum of the 10 regions). In essence, the DFT decomposes or separates a waveform into a series of sinusoids of different frequencies,