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Investigation of flow properties of metal powders from narrow particle size distribution to polydisperse mixtures through an improved Hall-flowmeter

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ABSTRACT

Initially, we critically examined the results provided by the improved Hall-flowmeter, based on bulk volume flow rate, with narrow particle size distribution metal powders (iron, aluminium and copper) of different sizes (fine to coarse) and shapes (nearly spherical to non-spherical). Binary and ternary mixtures of various combinations of fine (<100 μm) and coarse (>100 μm) metal powders at different size ratios and weight fractions were allowed to discharge from a mass flow hopper. The results show that the mass flow rate of polydisperse mixtures of metal powders is affected by four factors: the size ratio, the volume fraction of the smallest sieved fraction, the initial mass flow rate and the shape of metal powders.

1. Introduction

Flow of particles and granules in hoppers, silos and similar containers is important in many technologies such as the processing of minerals, grains, chemicals, pharmaceuticals and the metal powder industry. Discharge of particles from the hopper generates flow, and this resembles the laminar flow of viscous liquids. Free flowing powders are usually sought because they are easy to handle and hence do not frequently cause difficulties in production plants. The opposite is the case of cohesive or poorly flowing powders with unpredictable behavior [1,2]. Consequently, being able to determine the flow properties of a granular material is crucial to prevent serious problems during production processes, such as storage, handling and processing operations (flow from hoppers and silos, die filling, transportation, sieving, grinding, mixing, compression and packaging) [1,3–8].

For routine use in production, a flowability test must be robust and simple [9,10]. The flow behaviour of powders depends strongly on the conditions during processing, and there are multiple instruments and methods of testing to characterize this, according to the powders involved. Ultimately, the flowability test may be used for process analysis and contribute to improved production control, thereby assuring a consistent quality of the metal powder product [9]. The Hall-flowmeter has been widely used as a standard method to characterise powders in the powder metallurgy industry. It measures the time required to discharge powder under gravity through an orifice of the standard funnel (DIN ISO 4490, Fig. 1) with the top and bottom of the hopper exposed to the atmosphere (so that pressure at these locations is identical). From this the average mass flow rate can be determined [5,6]. However, the test offers only a means of comparison and evaluation because in the majority of operating conditions the powder does not flow through a small orifice.

Analytical prediction of the gravity discharge rate of granules from small orifices requires an explicit functional form incorporating the effects of (i) the size and shape of the discharge orifice, (ii) the size distributions and the shape of particles, and (iii) the inclination of the hopper walls [11,12]. There is little in the literature to date on the investigation of polydisperse flow fields in hoppers. The work of Standish and Collins [13] and Standish [14] concentrated on the effects of hopper geometry on the observed segregation behaviour of discrete particle mixtures. Another body of empirical work concentrated on the characterization of the discharge rates of particle mixtures from hoppers [14]. However, compared with the almost exhaustive work on the flow properties of monosized spherical or nearly spherical or non-spherical particles, the studies of flow properties of nearly spherical or non-spherical particles in particle mixtures (binary or ternary mixtures), using various combinations of fine (<100 μm) and coarse (>100 μm) particles, appear to be very limited.

The first objective of the present investigation is to improve the reliability of the Hall-flowmeter. Also, flow measurements using different size discharge orifices are plotted against the powder physical properties of very narrow particle size distribution powders, in order to enhance the understanding of the relationship between flowability and powder characteristics (e.g. particle size, size distribution and morphology etc.). Finally, experimental investigation of the flow of polydisperse powders in hoppers is carried out, using

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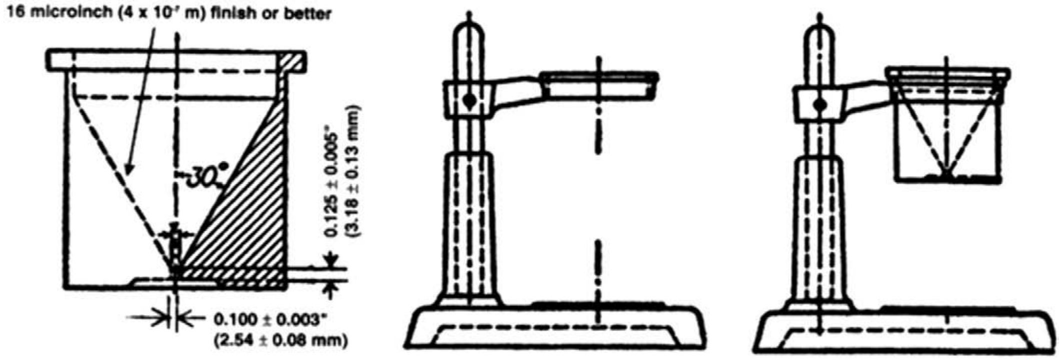

Fig. 1. Standard Hall-flowmeter [15].

binary and ternary mixtures of different size and shape powders, which are commonly employed in powder metallurgy.

2. Experimental methods

2.1. Materials

Four materials with various shapes were sieved to five narrow cuts (sieved fractions) to study the effect of powder size on flow. A Retsch (AS200) Analytical Sieve Shaker was used for sieving analysis according to the ASTM standard. Prior to starting sieving, the sieves were weighed and stacked up with the smallest one at the bottom and the largest one at the top (sieves with mesh openings of 45, 75, 106 and 150 μm and with ASTM sieve designation nos. 325, 200, 140, and 100, respectively). A pan was placed underneath the sieves to collect the particles which passed through all sieves. The materials were irregular aluminium, iron and copper and spherical copper (sieved fractions: Very Fine (VF) = −45 μm (≤45 μm), Fine (F) = +45 μm (45 μm < x ≤ 75 μm), Medium (M) = +75 μm (75 μm < x ≤ 106 μm), Coarse (C) = +106 μm (106 μm < x ≤ 150 μm), and Very Coarse (VC) = +150 μm (>150 μm)) supplied by AlPoCo, Hoganas, Ceram and Makin Metal Powder, respectively. The particles were kept dry before the measurements, thereby eliminating surface liquid capillary attraction and the chamber relative humidity of 40–50% was sufficient to allow dissipation of any static charges and eliminate the possibility of significant electric-static forces [16].

2.2. Enhancing the performance and reliability of the Hall-flowmeter measurement

The commercial irregular iron powder (free flowing powder) was used for the improvement of the reliability of the Hall-flowmeter measurements (supplied by Hoganas AB). Therefore, the operator errors during the Hall flow measurements could be minimized. The first step was to develop an apparatus to minimize the error of the flow time measurements resulting from the manual timing by the operator using a stopwatch. The apparatus consisted of a Hall-flowmeter, a balance, a serial interface and PC, as shown in Fig. 2. An A&D GF-200 precision balance with 0–200 g range, 1 mg resolution, 10 Hz sampling frequency and RS-232C serial interface was used for data acquisition. Prior to the experiments, the balance was calibrated using an ASTM standard 100 g mass. During the experiments, the Hall-flowmeter was positioned over the scale, and the powders were fed into the Hall-flowmeter. The powder passed through the Hall-flowmeter and was collected by a Petri dish resting on the scale. The mass of powder was automatically recorded and transferred directly to a PC and stored as text data files. The files were then processed using a program for generating plots of the mass accumulation versus time, as illustrated in Fig. 2. Fig. 2B also illustrates the stages of flow, namely 1) initial transient, 2) pseudo-steady and 3) final transient [17]. The slope of the plot gives the mass flow rate of the powder. The pseudo-steady (or funnel flow, an active flow channel forms above the outlet with non-flowing powder at the periphery) stage was used for measuring the mass flow rate, as this ensures that there is powder-

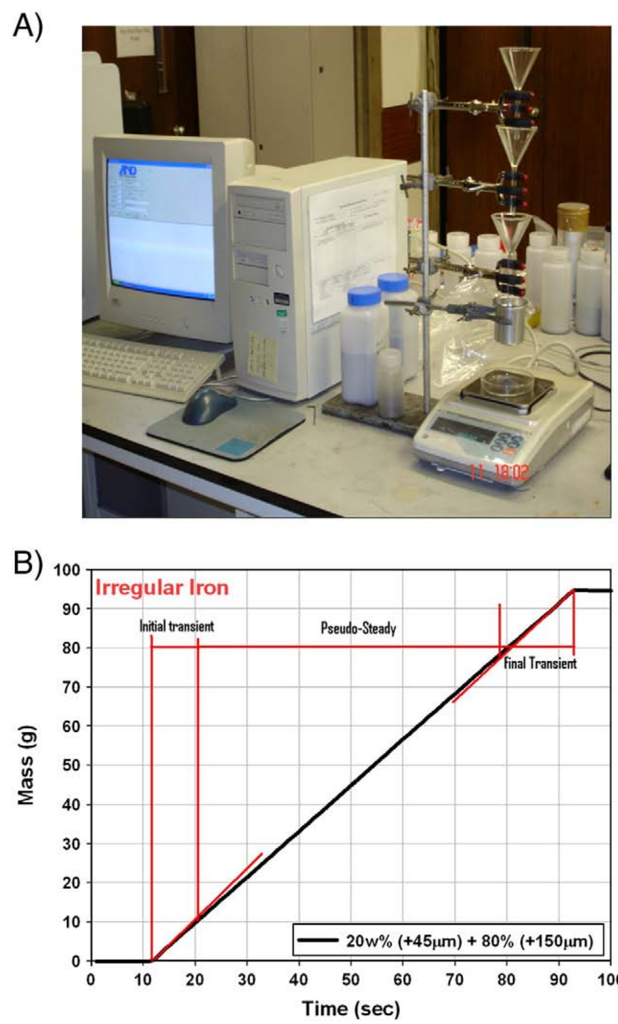

Fig. 2. (A) Description of the apparatus: Hall-flowmeter, Precision Balance, RS Com Ver. 2.40 Serial Interface & 3 Funnels. (B): Typical graph of mass flow rate showing the stages of flow of an irregular iron binary mixture.