Experimental Study of Mass Flow and Apparent Density in Powder Metallurgy Die Filling

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Abstract Die filling is the first step in the process of powder compaction. The density distribution after die filling depends on the powder properties and the method of filling. In this work the authors study the effects of powder characteristics, size and morphology, and shoe speed on the type of mass flow during the filling and the resulting density distribution. Experimental results for different powders and die geometries are presented. Three flow regimes have been identified and their influence on apparent density is discussed.

Keywords: granular materials, transfer powder, shear band, die filling.

1. Introduction

The initial density distribution inside the compacting die depends on type of metallic powder, filling method and the geometry of the die [1-3]. The shape and the size of the powder are the two more relevant parameters regarding the flow mechanisms due to their influence on the friction among particles and the final degree of packing [4].

The shoe speed (v_s) determines the kinetic energy of particles influencing inertial effects. Finally, the geometry and superficial finish of the die have a strong frictional effect on the mass flow by means of the interaction between the particles and the walls of the die.

In this work a broad study on the effect of all these parameters in the mechanisms of powder flow and initial density is presented.

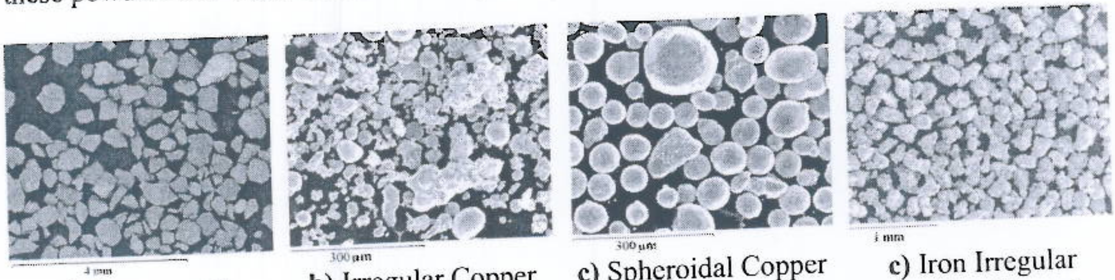
2. Experimental Techniques and Material Characterization

A filling device has been designed consisting a horizontal shoe and a die both transparent.

The shoe is moved pneumatically with an accurate control of the velocity. Powder filling is recorded by means of a high speed (80 fps) video camera.

The die has also been instrumented with high sensitivity gages to allow the measurement of the mass flow and the variation of apparent density with the filling height.

Four different materials have been used for this study: coloured sand, spheroidal copper, irregular copper and irregular iron (sponge iron). Fig.1 shows the morphologies of these powders and Table I some of their physical and morphological properties.



a) Coarse sand. Lognormal distribution.
b) Irregular Copper Powder. Exponential distribution.
c) Spheroidal Copper Powder. Normal distribution.
c) Iron Irregular Powder. Normal distribution.

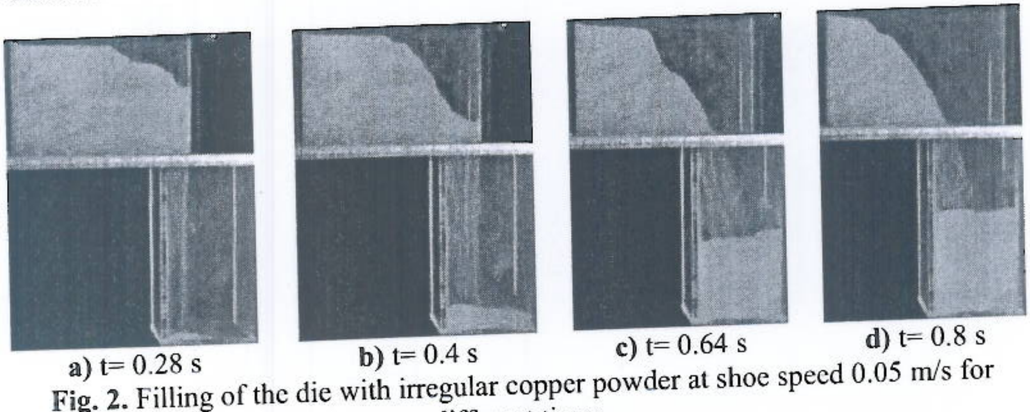
Fig. 1 Morphology and particle size distribution of the four employed materials

Table I. Physical and morphological properties of the materials.

Material	*Coarse Sand*	*Irregular Copper P.*	*Spheroidal Copper P.*	*Irregular Iron P.*
Density material (ρ) [gr/cm^3]	2.43 ± 0.01	8.96 ± 0.01	8.96 ± 0.01	7.86 ± 0.01
Part. diameter ($d_P \pm \Delta d_p$) [mm]	0.793 ± 0.24	25.3 ± 18.4	66.24±18.49	0.233 ± 0.06
Porosity (P) [%]	Compact	Compact	Compact	15
Morphology	Faceted polyhedral shape	Irregular shape	Spheroidal shape	Irregular shape

3. Flow Regimes and Mass Flow

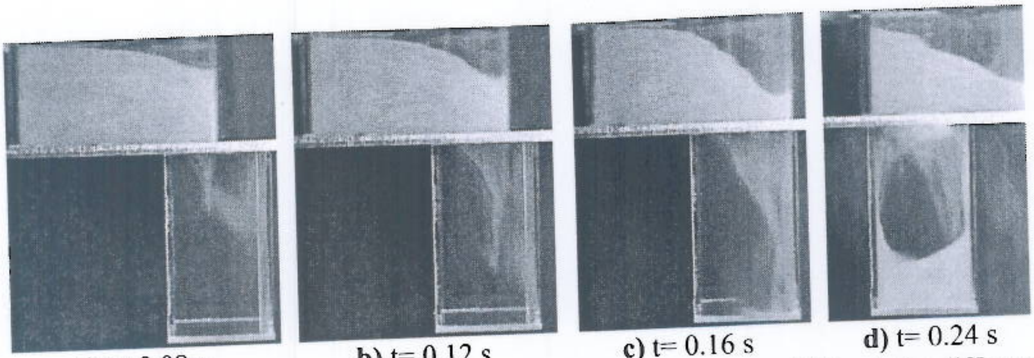
Shoe speeds of 0.05, 0.1, 0.2, 0.3, 0.4 and 0.5 m/s have been employed. The way of flow change with the particle size and speed. At low shoe speeds flow is mainly by successive and discontinuous avalanches of powder as shows the figure 2



a) t= 0.28 s **b)** t= 0.4 s **c)** t= 0.64 s **d)** t= 0.8 s

Fig. 2. Filling of the die with irregular copper powder at shoe speed 0.05 m/s for different times.

When speed increases powder flow becomes more continuous as shows the figure 3. Small particles also favour a discontinuous way of mass flow.



a) t= 0.08 s **b)** t= 0.12 s **c)** t= 0.16 s **d)** t= 0.24 s

Fig. 3. Filling of the die with irregular copper powder at shoe speed 0.3 m/s for different times.

In Fig.4 the combinations of size and velocities giving place to the two regimes of mass flow are represented. The transition from avalanches to continuous flow is not well delimited existing, therefore, an area were mass flow shows characteristics of both regimes. These two regimes have also been observed previously with rolling cylinders [5].

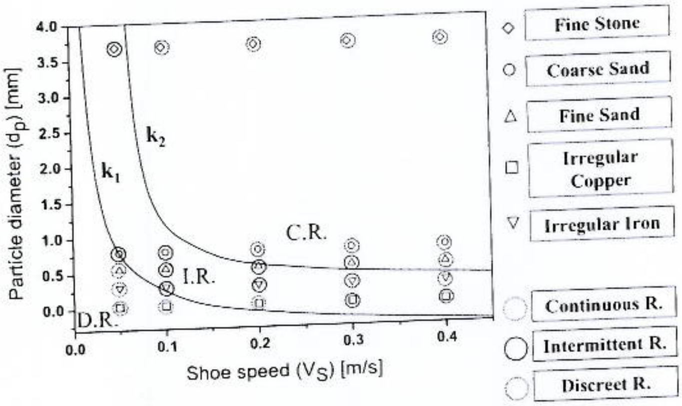


Fig. 4. Three regimes are observed during the discharge process as a function of the shoe speed: discrete avalanche regime, intermittent flow regime and continuous flow regime.

The areas were each regime is well defined can be delimited by means of hyperbolic equations of the type:

$$k_i=(d_p-b_i)\cdot(v_s-a_i)^n \qquad (1)$$

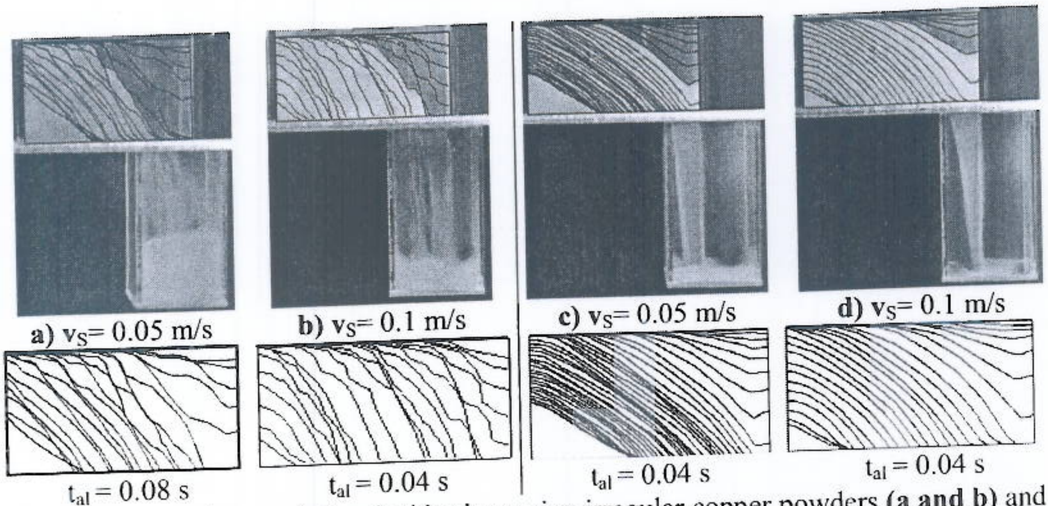
where k_1 and k_2 are constants defining the width of both regimes. The meaning of the asymptotes a2 and b2 (a1=b1=0) is:

a_2: for $v_s < a_2$ the flow regime is never continuous regardless of the particle size
b_2: for $d_p < b_2$ the flow regime is never continuous regardless of the shoe speed

The value of n is 1 when the curve is symmetric respect to the line $d_p = v_s$.

For each filling regime the mass falling inside the die has been measured, showing that when an avalanche regime is acting the mass increases in an oscillating way.

The morphology of the powder plays also an important role. The spheroidal copper has shown always a continuous regime as shows the figure 5.



a) v_S= 0.05 m/s b) v_S= 0.1 m/s c) v_S= 0.05 m/s d) v_S= 0.1 m/s

t_{al} = 0.08 s t_{al} = 0.04 s t_{al} = 0.04 s t_{al} = 0.04 s

Fig. 5. Free surface evolution inside shoe using irregular copper powders **(a and b)** and spheroidal copper powders **(c and d)**. Where t_{al} is the time between two adjacent lines.

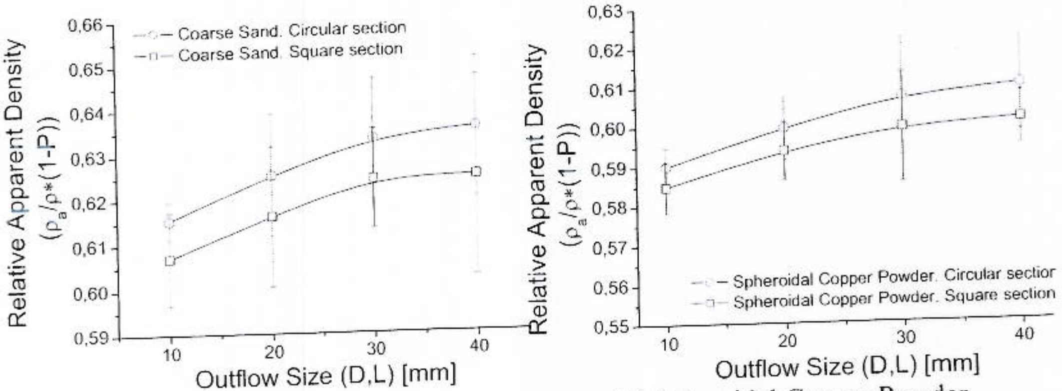
4. Relative Apparent Density Variations (ρ_{ra}) with Die Shape Factor (S_o) and Die Height

To compensate for the sponge nature of the irregular iron the apparent density has been corrected by taking into account the porosity P of the particles. In this way the corrected relative apparent density ρ_{ra} is not defined with respect to the bulk material density ρ but to the particle density ρ_{ra}, where:

$$\rho_p = \rho * (1 - P) \qquad (2) \qquad \text{and} \qquad \rho_{ra} = \frac{\rho_a}{\rho_p} \qquad (3)$$

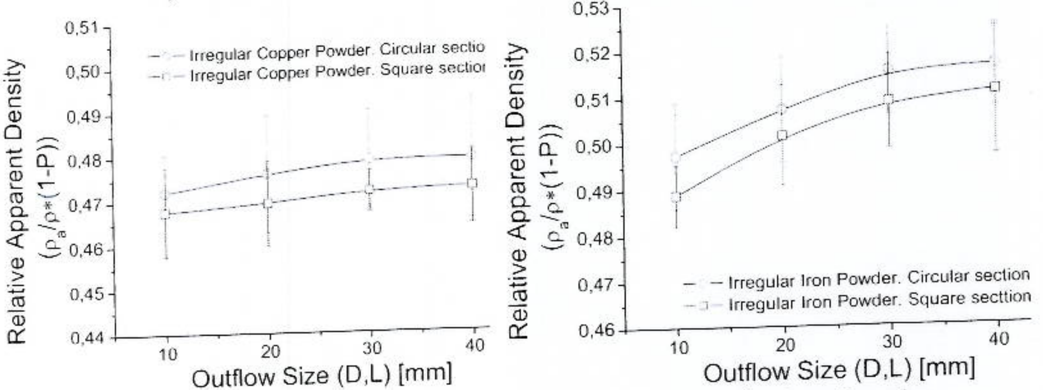
Fig. 6 shows the behaviour of the apparent density for each of the powders studied. The value of ρ_{ra} increases with the section of the dies up to a point from which the separation between walls has no longer effect.

Apparent density is always higher in cylindrical dies. Irregular copper seems less affected by the size of the mold. Similar behaviour has been observed in a previous study of Ames S.A. [6].



a) Coarse Sand

b) Spheroidal Copper Powder



c) Irregular Copper Powder

d) Irregular Iron Powder

Fig. 6. Relative apparent density variations with outflow size for both geometries

In order to try to take into account the effect of the different die geometries a form factor S_0 has been defined.

This factor relates the area (A_0) with the perimeter (P_0) of the section of the mould. It is given by expression (4) and it has the maximum value 1 for a circular section.

$$S_o = \frac{4 \cdot \pi \cdot A_o}{P_o^2} \quad (4) \qquad S_o^n = \frac{\rho_{ra}(square)}{\rho_{ra}(circular)} \quad (5) \qquad \text{where} \quad n = \frac{\ln\left(\dfrac{\rho_{ra}(square)}{\rho_{ra}(circular)}\right)}{\ln(S_o)} \cong 0,05 \quad (6)$$

Fig.7 shows how the expression (5) enables to unify the behaviour of a powder in the different dies.

The exponent n is small (0.05) in all cases indicating that the influence of the mould geometry is less important than that of the type of powder.

The variation of the apparent density with height inside the die for the case of spheroidal copper powder is shown in Fig.8. It is interesting to see that density is higher at the bottom of the die that in the upper layers.

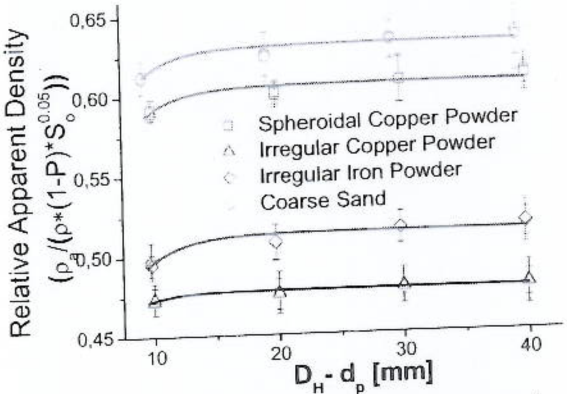
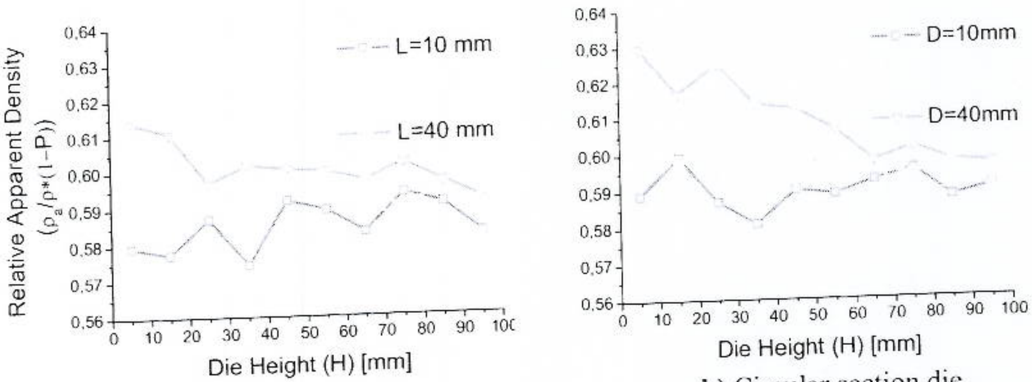


Fig. 7. Fitting of shape factor for square and circular dies (n=0.05)

This is due to the compaction of these lower layers by the powder falling over during the filling of the die. In the square dies and with the smaller sections the friction with the walls opposes this effect.



a) Square section die

b) Circular section die

Fig. 8. Relative apparent density variations using spheroidal copper powder

6. Conclusions

Three flow regimes have been observed in the die filling tests. At low shoe speeds a regime of discontinuous avalanches prevails while at high shoe speeds the flow regime is of continuous character. At intermediate speeds a transitory regime of intermittent flow occurs. Apparent density decreases with decreasing die section. An expression has been proposed that unifies the variation of apparent density with the die section and the particle size.

The spheroidal particle morphology favours the existence of higher densities at the bottom of the die. With irregular shaped particles the inverse behaviour is observed, particularly in dies with small section.

7. Acknowledgments.

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