Application of Fluidization for Powder Delivery and Die Filling

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Abstract

Production of high quality PM parts using the conventional press and sinter approach requires uniform fill of die cavities, which in turn requires uniform and consistent delivery of particulate material to the fill shoe. The delivery of particulate material is influenced by the hopper design, the hose connecting the hopper and fill shoe, and the fill shoe design. A non-uniform powder delivery to the fill shoe results in variations in head pressure that translates into variations in part weight and dimensions. Using dry gas at low pressure and flow rate, we have been able to eliminate the friction along the interface between the hose and powder, and achieve uniform powder delivery to the fill shoe. Fluidization of the powder within the fill shoe will further enhance the uniformity in die filling and improves part dimensional control. The technology is demonstrated for compaction of small parts on low tonnage presses and large parts on high tonnage presses, and for different materials, including metals and ceramics.

Introduction

The PM process is a cost-effective process for net shape parts. It uses dry particulate material with irregular shape and typically relies on the addition of binders and lubricants to achieve acceptable powder flow rates for production applications. As a result of variations in particle shape and size as well as environmental conditions, large variations in flow behavior are observed during production. In addition, the delivery of powder from the hopper to the fill shoe for die filling depends on the hopper design and the hose connecting the hopper and the fill shoe. As the fill shoe is translated back and forth above the die cavity, the hose profile changes and powder flow within the hose is affected. The change in profile also causes variations in the powder head during filling, which in turns causes variations in filling within the die cavity.

Improvements in dimensional control and part quality requires the delivery of a uniform and consistent powder flow to the fill shoe for die filling and a fill shoe that can improve the quality of the fill. Using dry gas at a low pressure and flow can be used to eliminate or greatly reduce interparticle friction and wall friction between the powder particles and hose. Using gas will reduce the dependence on the use of binders and lubricants, additives that have to be burned out during the delubing and sintering cycle in order to achieve acceptable properties. The challenge is to use the appropriate gas pressure and flow to achieve the desired results. Once powder flow is regulated, the next step is to control the die filling process.

To achieve these objectives a fluidized flow tube was designed to improve the powder flow and the delivery of powder from the hopper to the fill shoe. A fluidized fill shoe was designed to isolate the filling process from the powder delivery step and achieve uniform fill of die cavities. This approach is demonstrated for small parts on a 6T press and for a large gear on a 220T press.

Powder Delivery

One implementation of fluidization for powder delivery is illustrated in Figure 1 in which a "Fluidized Flow Tube" is inserted along a flexible hose. Dry gas is introduced at low pressure and flow rate at the bottom of the tube. Most of the gas permeates through the powder and is vented through the top screen while the rest travels upstream through the hose and is vented through the hopper. The gas acts as a lubricant and creates a frictionless interface between the tube and the powder particles. As a result, the powder slides quickly and the rate of powder discharge increases. In addition, the gas fluidizes the powder as it travels through it. If the gas is introduced at a high pressure and flow rate, it creates turbulence that negatively influences powder flow. The gas that travels upstream through the hose reduces the wall friction and interparticle friction. As a result, powder flows to the fluidized segment at an increased rate. The overall result is a two to three fold increase in powder flow rate depending on powder flow characteristics. For example, a two-fold increase in powder flow rate is observed for iron-based systems, and a three-fold increase is observed for spray-dried ceramic material.

In addition to the increase in powder flow rate, the gas acts as an added lubricant within the powder particles, creates small separation between particles and thus helps to eliminate the effects of variations in powder characteristics, such as variations in particle shape and size distribution, powder lot to lot variations, and variations in ambient conditions, which typically influence both interparticle friction and wall friction. The result is a uniform powder flow without the introduction of any solid matter that needs to be removed at a later stage.

In summary, the use of dry gas at low pressure and flow rate results in a predictable, uniform and increased powder flow rate. Fluidization of a short segment along the hose results in a uniform and consistent powder flow as well as two- to three-fold increase in powder flow rate, depending on powder characteristics.

(a) Fluidized Flow Tube **(b) Powder Flow**

Figure 1. Schematic of the fluidized flow tube system.

Powder Flow Rate

Flow rate measurements were made for different metal powders with and without lubricant, and for ceramic powders with and without lubricants. Some of the measurements on metal powders were presented in Zahrah et. al. [1]. Powder flow rates are reported for 50g of powder flowing through a Hall flow meter, a standard method for characterizing powder flow. To quantify the increase in flow rates as a result of fluidization, a "fluidized flow meter" was built. This fluidized flow meter has the same design, including funnel size, slope and orifice size, as the standard Hall flow meter except that the side has a porous distributor plate which allows the gas to go through and fluidize the powder. The results are summarized in Table I for metal powders and in Table II for ceramic powders.

At low gas pressure, the time for 50g of powder to flow through a Hall flow meter is reduced by 31 to 55% for metal powders and by 68 to 80% for ceramic powders. In addition, fluidization enables flow for bronze w/3% graphite, which does not flow through a Hall flow meter, at flow rates comparable to those of flowable powders. The results on flow measurements provide further evidence of the effectiveness of dry gas as a lubricant to minimize interparticle friction and increase flow rates. In addition, different types of flow were observed during the experiments. The flow using a standard Hall flow meter can be characterized as a "funnel flow" and some "stick-slip" motion was observed. Using the fluidized flow meter, the flow can be characterized as "mass flow" and it was continuous with the powder surface remaining nearly horizontal.

Table I. Flow time for different metal powders (50g each) under gravity and fluidized conditions.

Powder Type	*Hall Flowmeter*	*Fluidized Flowmeter*		*Improvement (%)*	
		1 psi	*2 psi*	*1 psi*	*2 psi*
FN0208 A1000B	*30.7*	*19.5*	*17.9*	*36.3*	*41.2*
F-0000/MH100 w/ 0.75% lub.	*31.7*	*22.0*	*20.1*	*30.7*	*36.5*
45 P Hoeganaes	*29.6*	*20.1*	*18.8*	*32.0*	*36.6*
OMG 90-10 Bronze PMB-8	*37.5*	*16.6*	*15.1*	*55.7*	*59.6*
Pyron Bronze w/ 3% graphite	*no flow*	*19.3*	*16.9*	*-*	*-*
Magnetic Material	*24.2*	*15.2*	*-*	*37.2*	*-*

Table II. Flow time for different ceramic powders (50g each) under gravity and fluidized conditions.

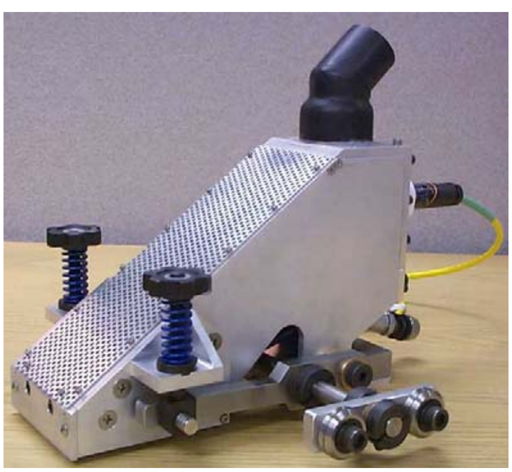
Powder Type	*Hall Flowmeter*	*Fluidized Flowmeter 0.5 psi*	*Improvement (%)*
Ceramic Material 1 w/ lubricant	*62*	*20*	*67.7*
Ceramic Material 1 no lubricant	*70*	*22*	*68.6*
Ceramic Material 2 w/ 0.5% lubricant	*108*	*23*	*78.7*
Ceramic Material 2 w/ 1% lubricant	*105*	*22*	*79.1*

Fluidized Fill Shoe for Die Filling

One area where further improvements can be made is in the filling of the die cavity. Issues critical for production of high quality, net-shape parts are reduction in weight variation from part to part, and uniform fill of die cavity to reduce distortion during sintering and reduce density variations in the final part. Progress in these areas will result in improvements in dimensional control.

A fluidized fill shoe system was developed to improve the speed and uniformity of filling complex-shaped die cavities [1]. A schematic of the system is illustrated in Figure 2(a). The fluidized fill shoe again uses a dry gas to coat particles and separate them, thereby greatly reducing interparticle friction and increasing powder flow rates. This system is used for presses 30T and higher. For low tonnage presses, such as 4T to 15T presses, a system shown in Figure 2(b) is used. In this case, the system has two chambers, a transport and a delivery chute, plus a gas control box. The powder is fluidized in each chamber separately by regulating the flow of gas to each chamber independently.

Fluidization of the powder in the transport results in the elimination of the effects of variations in powder level in the hopper on die filling. As a result, the die filling operation is isolated from the powder delivery. Fluidization of the powder in the delivery chute results in a uniform and homogenous powder mix in the delivery chute and improved die filling. In addition, the gas around the inner surface of the delivery chute prevents the build up of material within the delivery chute and eliminates any residual powder.



(a) Fluidized Fill Shoe

(b) Miniature Fill Shoe

Figure 2. Schematic of fluidized fill shoe system.

Fluidized Fill Shoe Applications

Two applications of the fluidized fill shoe are discussed: one with the miniature fluidized fill shoe and the other with the medium size fluidized fill shoe.

Ceramic Fuse Body

This ceramic fuse body is molded on a 6T Pentronix press. The fill depth is about 25mm (1in.) and the wall thickness is 0.64mm (0.025in.). Initially the die had four cavities. Non-uniform filling of the die cavities resulted in variations in green weight from part to part and in non-uniform shrinkage during sintering leading to a taper along the length.

The use of the miniature fluidized fill shoe enabled the use of a die tool with seven cavities while reducing the weight variations from part to part and reducing the taper in the length after sintering. The first indicator of fill performance was the increase in part weight. Fluidization of the material before filling enabled the uniform delivery of the powder to the die cavity and increased the amount of the fill as a result of a reduction in frictional effects between the powder and die wall. In addition, the use of the fluidized fill shoe eliminated the packing of the powder inside the delivery chute and reduced the amount of maintenance required during usage.

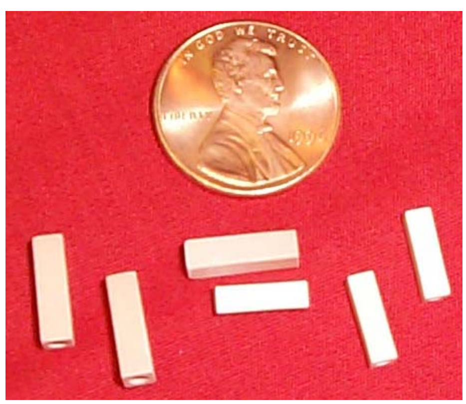


Figure 3. Ceramic Fuse body parts used to demonstrate the applicability of the fluidized fill shoe for small parts applications.

Large Size Gear

A large size gear with a weight of 766g was used to demonstrate the applicability of the medium size fluidized fill shoe. The parts were molded on a 220T press. Parts were made at the regular production rate, first using the fluidized fill shoe and subsequently using the standard gravity fill shoe and then a rotary shoe. Weight and length measurements were then made on green parts.

The variation in part weight is illustrated in Figure 4 and the statistical information on part weight and length is summarized in Table III. The standard deviation on part weight was reduced from 1.194g using the standard gravity fill shoe to 0.417g using the fluidized fill shoe while the range was reduced from 5.8g to 1.9g. The standard deviation on part length was reduced from 0.059mm (0.0023in.) to 0.044mm (0.0017in.) while the range was reduced from 0.201mm (0.0079) to 0.145mm (0.0057).

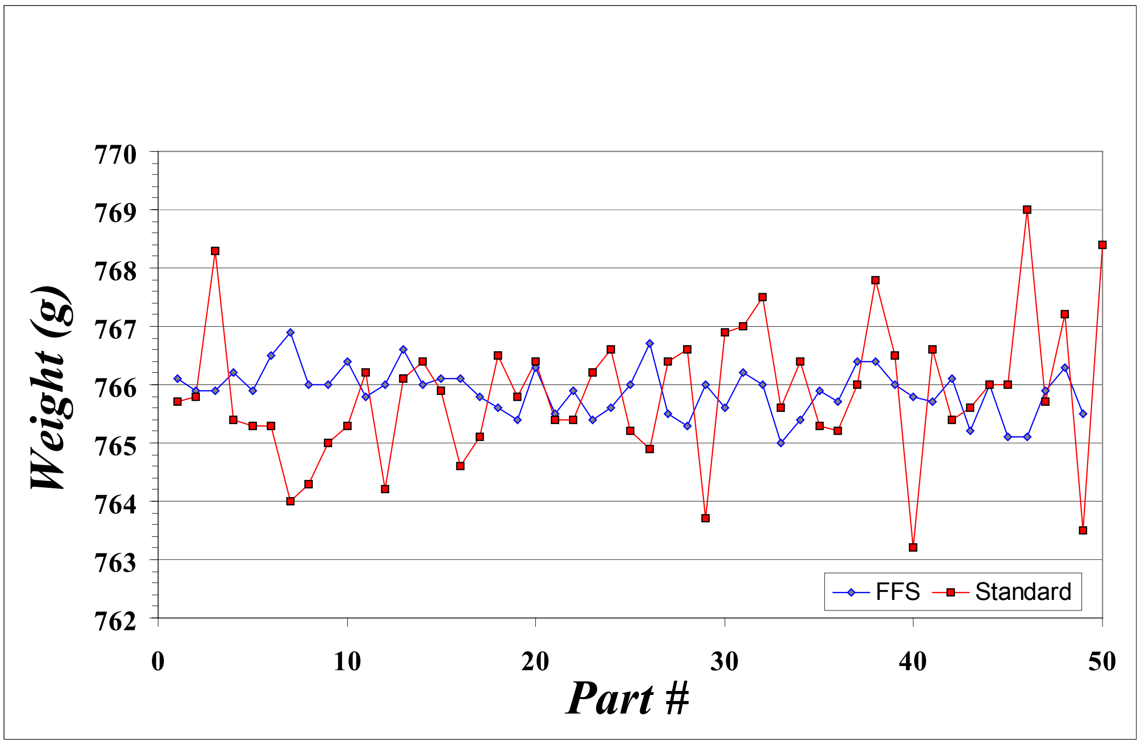


Figure 4. The use of the fluidized fill shoe improves weight tolerance for the large gear by a factor of three.

Table III. Statistical variations in weight and length for the large gear using fluidized and standard filling techniques.

Weight Capability

	Fluidized Fill Shoe	*Standard Feedshoe*	*Rotary Feedshoe*
Range	***1.9 g***	***5.8 g***	***3.2 g***
Std. Dev.	***0.417***	***1.194***	***0.805***

Length Variation Over 5 Parts

	Fluidized Fill Shoe	*Standard Feedshoe*	*Rotary Feedshoe*
Range	***0.145 mm***	***0.201 mm***	***0.219 mm***
Std. Dev.	***0.044***	***0.059***	***0.054***

Summary

Fluidization using dry gas at low pressure and low flow can be used to achieve uniform powder flow and increase powder flow rates. The gas acts as an effective lubricant without adding any solid lubricant that needs to be removed. Using this concept of fluidization, a fluidized flow tube was designed and demonstrated for uniform transfer of powder material from the hopper to the fill shoe. Further fluidization of the powder in the fill shoe before die filling will improve dimensional control and the quality of the final parts. The results for the fuse body and large gear demonstrate the capability of the fluidized fill shoe to help produce high quality net shape parts. The reduction in standard deviation on weight and thickness allows the user to bring a process under tighter control and eliminate or greatly reduce scrap rates.

References

1. T.F. Zahrah, R. Rowland, and G. Gasbarre, Jr. “Fluidized Fill Shoe for Uniform Die Filling,” P/M Science & Technology Briefs, Vol. 1, N0.3, 1999.