Use of Fluidization for Die Filling Applications

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Abstract

The flow of dry particulate materials is influenced by many variables, including particle shape and size distribution, density, and composition. As a result, it is to some extent unpredictable and non-uniform. In Powder Metallurgy (PM) applications, binders and lubricants are used to improve powder flow. However, these additives can negatively influence compaction and they have to be eliminated during the delubing and sintering cycle. Fluidization, with dry gas injected at low pressure and low flow rate, can be used to minimize the effects of the many variables that influence particulate material flow, and to achieve a uniform and consistent flow rate. Once the flow is controlled, die filling can be improved by regulating the powder flow rate and the deposition of the powder into the die cavity. The result is increased user control of the powder delivery and filling processes, which leads to improved dimensional control and compact quality.

Introduction

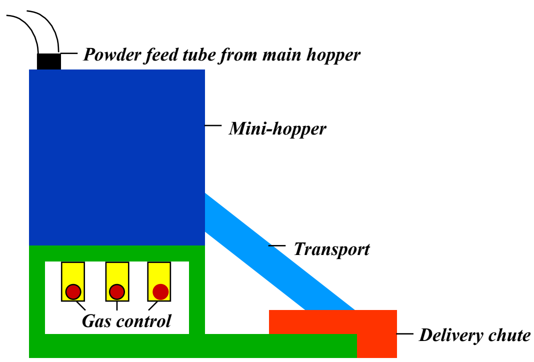
The conventional PM process enables compacts to be made cost-effectively with high quality. However, expansion of the applications using conventional PM depends on the ability of processing parts with improved quality and dimensional control. This can be achieved by regulating the powder flow to achieve a uniform and consistent powder flow rate, and by controlling the die filling to get a uniform and consistent powder fill, and reducing weight variation from compact to compact.

Traditionally, the PM industry has relied on the use of binders and lubricants to improve powder flow. However, these additives have to be burned out during the delubing and sintering cycle in order to achieve acceptable properties. Rather than using solid additives, dry gas can be used to lubricate the powder particles, minimize internal friction between particles, and minimize wall friction between the powder particles and container wall. By reducing friction, the powder flow rate is greatly increased and, most importantly, the flow is uniform and consistent.

To achieve these objectives dry gas is introduced below the powder at low pressure and low flow rate, and is vented to prevent build up of pressure within the particulate material bed. This approach also prevents powder segregation for a material with a wide particle size distribution and for alloys with materials of different densities.

Fluidized Fill Shoe System

A fluidized fill shoe system was developed to increase powder flow rates, and improve the speed and uniformity of filling complex-shaped die cavities. By flowing gas through a bed of solid particles from the bottom to the top, the bed is loosened and fluidized, and particles are easy to move. A schematic of the concept and a unit that fits on a 50T press or larger are illustrated in Figure 1. The fluidized fill shoe uses a dry gas, such as air, argon or nitrogen, to "coat" particles and separate them, thereby greatly reducing interparticle and wall friction, and increasing powder flow rates. The gas provides a transport mechanism reducing interparticle friction and powder/wall friction, and thereby reducing the need for bulk lubricants in the powder blend.



(a) Concept

(b) Production Unit

Figure 1. Schematic of fluidized fill shoe system and actual implementation.

The fluidized fill shoe system has four main components:

1. **Mini-hopper.** The mini-hopper receives powder from the main hopper and is the intermediate storage unit. It isolates die filling from variations in head pressure in the powder hose and main hopper.

2. **Transport.** The transport supplies powder from the mini-hopper to the delivery chute, while keeping the powder in a fluidized state.

3. **Delivery chute.** The delivery chute functions as the powder discharge unit directly above the die cavity.

4. **Gas control unit.** The gas control unit is used to control the gas moisture content and regulate powder fluidization in relation to the movement of the fill shoe on the press.

The powder is fluidized in each chamber of the fluidized fill shoe, namely, the mini-hopper, the transport and the delivery chute, by regulating the flow of gas to each chamber independently.

Particulate Material Flow

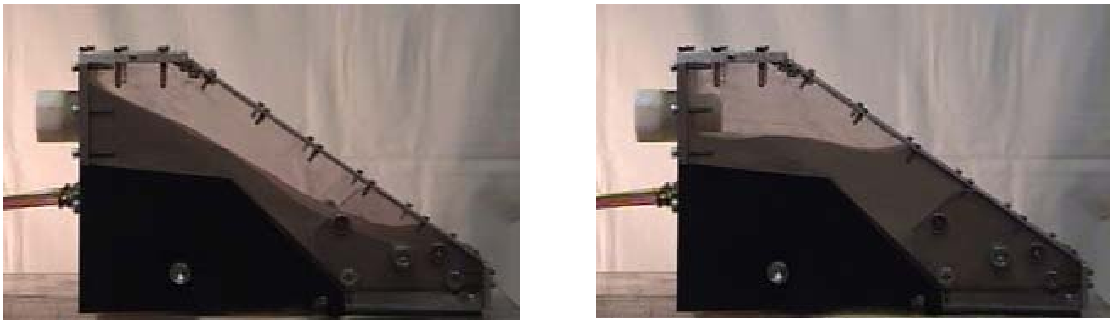
Fluidization can be used to improve and control the uniformity and consistency of particulate material flow. By adjusting the gas flow pressure and flow rate, the powder flow within the fill shoe can be controlled. To demonstrate how powder flow can be controlled, a fluidized fill shoe was assembled with clear sides to monitor the powder flow within the fill shoe during powder discharge. Two experiments were performed: in one experiment the gas is turned off to simulate the functionality of a gravity fill shoe, and in the other the gas is turned on to simulate the functionality of a fluidized fill shoe.

In the first experiment, the fill shoe is filled with powder while the gas is turned off. The gas is kept off while the fill shoe is pushed forward on top of a cavity to allow the powder to be discharged. As the powder is being discharged, the powder surface within the fill shoe is at an angle equivalent to the shearing angle of the material. One snap shot during discharge of a gravity fill shoe is illustrated in Figure 2(a). In the second experiment, the fill shoe is filled with powder while the gas is turned off. The gas is then turned on and the fill shoe is pushed forward on top of the same cavity to allow the powder to be discharged. As the powder is being discharged, the powder surface within the fill shoe remains horizontal until the fill shoe is empty. One snap shot during discharge of a fluidized fill shoe is illustrated in Figure 2(b).

The effects of fluidization are to:

1. Refill the transport and delivery chute at a rate faster than the discharge rate into a die cavity, as a result of the increase in powder flow rate, which reduces the effects of variation in head pressure; and

2. Maintain a horizontal powder level within the fill shoe as the powder is being discharged, which results in uniform head pressure during die filling.



(a) Gravity Fill Shoe **(b) Fluidized Fill Shoe**

Figure 2. Powder surface during discharge of fill shoe is at an angle when the gas is turned off to simulate a gravity fill shoe and is horizontal when the gas is turned on to simulate a fluidized fill shoe.

Head Pressure Verification

An experiment was designed to demonstrate the ability of the fluidized fill shoe system to isolate die filling from variations in head pressure. A die for a thick bushing with 2.25-in (57.15mm) OD, a 0.312-in (7.92mm) wall thickness and 1-in (25.4mm) fill depth was used. First, 20Kg (50lbs) of iron powder (SC 100.26 Hoganas powder) were loaded in the main hopper of a 200T Gasbarre press. Parts were pressed using the standard gravity fill shoe at 18 strokes per minute (SPM) and weighed sequentially as they came off the press until all the powder was used. Next, the fluidized fill shoe was installed on the press and another 20Kg (50lbs) of the same powder were then loaded in the main hopper. Parts were then pressed at the same speed using the fluidized fill shoe until all the powder was used. Again all parts were weighed sequentially. The results are illustrated in Figure 3.

An examination of the results shows that

- Using the gravity fill shoe:
    1. Part weight stabilizes after about 20 parts are pressed.
    2. Part consistency is lost as the powder level in the main hopper drops.
- Using the fluidized fill shoe:
    1. Part weight stabilizes almost immediately as parts are pressed.

2. Part consistency is maintained until the main hopper is empty.

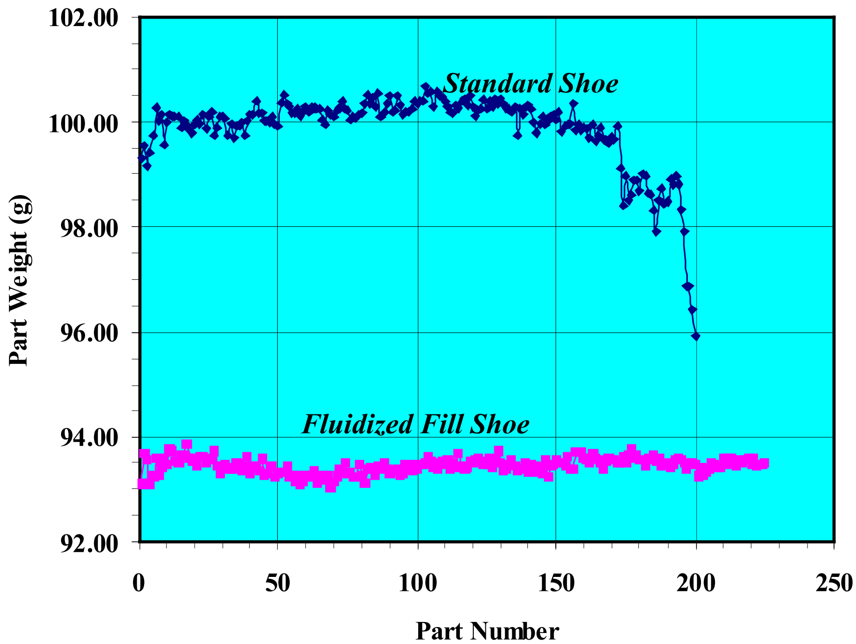


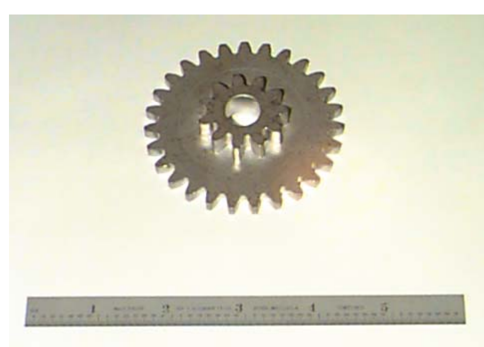
Figure 3. Variation in part weight from part to part using (a) a standard gravity fill shoe and (b) a fluidized fill shoe.

These results indicate that the die filling operation can be isolated from the powder delivery, which helps improve part consistency and dimensional control. By using fluidization, the mini-hopper isolates die filling from fluctuation in the powder head in the powder hose and the main hopper.

Fluidized Fill Shoe Applications

Two applications of the fluidized fill shoe are discussed: a thin-wall bushing and a two-level sprocket gear, illustrated in Figure 4.

(a) Thin wall bushing



(b) Two-level sprocket gear

Figure 4. Parts used to demonstrate the advantages of the fluidized fill shoe.

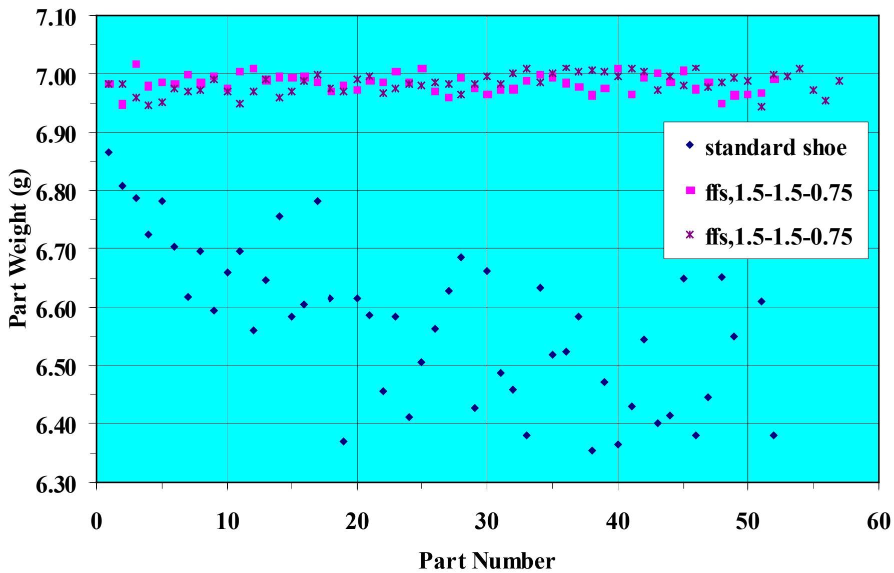
Thin Wall Bushing

The thin wall bushing has a 31.75mm (1.25in) OD and a 1.09mm (0.043in.) wall thickness. The fill depth is 20mm (0.787in). The two main objectives of this set of experiments are to evaluate (1) the performance consistency and repeatability of the fluidized fill shoe, and (2) the fill consistency and weight control for parts with a thin wall using fluidization. The experiments were performed on a 30T Gasbarre/Tamagawa press at 10 SPM using flowable and "poorly-flowable" iron-based alloys.

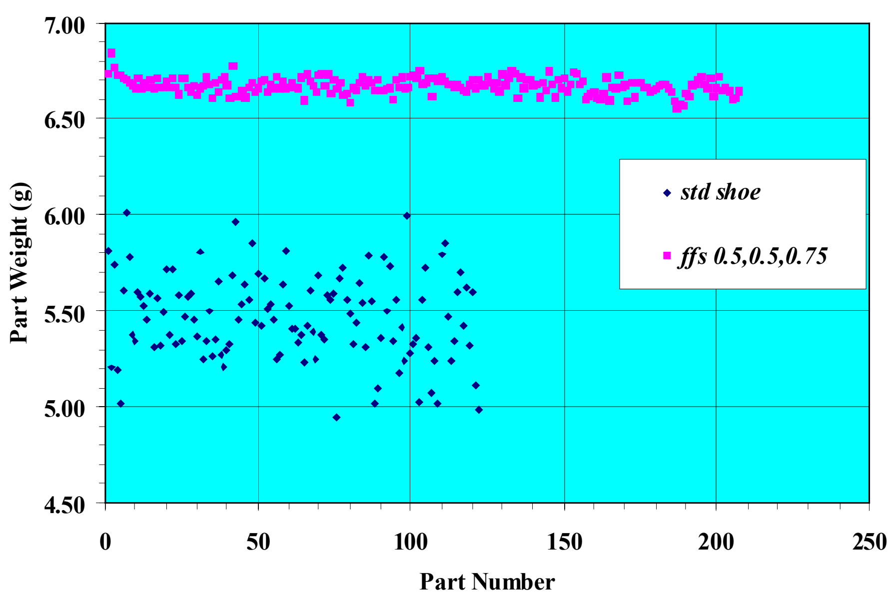
Fluidized fill shoe consistency. The bushing is made using a flowable iron-based alloy. The fluidized fill shoe was installed on the press and gas pressure was set at 1.5psi for the mini-hopper and transport and at 0.75psi for the delivery chute. Parts were made at 10 SPM and weighed sequentially from first to last. The fluidized fill shoe was then removed and a standard fill shoe was installed on the press. Parts were then made at the same speed using the standard gravity fill shoe and weighed sequentially. Subsequently, the standard fill shoe was removed and the fluidized fill shoe was re-installed on the press. Using the same gas pressure settings, parts were pressed and weighed sequentially. The results for weight variation are illustrated in Figure 5(a).

An examination of the experimental results leads to several observations on the performance of the fluidized fill shoe. First, the fluidized fill shoe results in a much improved weight consistency from part to part. Using the fluidized fill shoe, the weight range is 0.069g and the standard variation is 0.015 during the first run, and 0.066g and 0.017, respectively, during the second run. Using the gravity fill shoe, the weight range is 0.509g and the standard variation is 0.131. Second, the use of the fluidized fill shoe results in an increase in part weight for the same fill depth. Both of these effects are the direct result of improved consistency in powder flow and improved fill conditions through fluidization. Third, the fluidized fill shoe performance is consistent and repeatable for the same gas pressure settings.

Fill consistency and weight control. In this set of experiments, the bushing is made using a poorly-flowable iron-based alloy. The fluidized fill shoe was installed on the press and gas pressure was set at 0.75psi for the mini-hopper, the transport and the delivery chute. Parts were made at 10SPM and weighed sequentially as they came off the press. The fluidized fill shoe was then removed and a standard fill shoe was installed on the press. Parts were then made at the same speed using the standard gravity fill shoe and weighed sequentially. The results for weight variation are illustrated in Figure 5(b). It is apparent from the results that the poorly flowability of the powder results in very poor quality thin-wall compacts. The use of gas to lubricate powder particles results in a consistent powder flow. In addition, slight separation of powder particles as they are dropped on top of the die cavity will allow the air within the die cavity to escape and results in great improvements in filling.



(a) Fluidized fill shoe performance and repeatability with flowable iron alloy



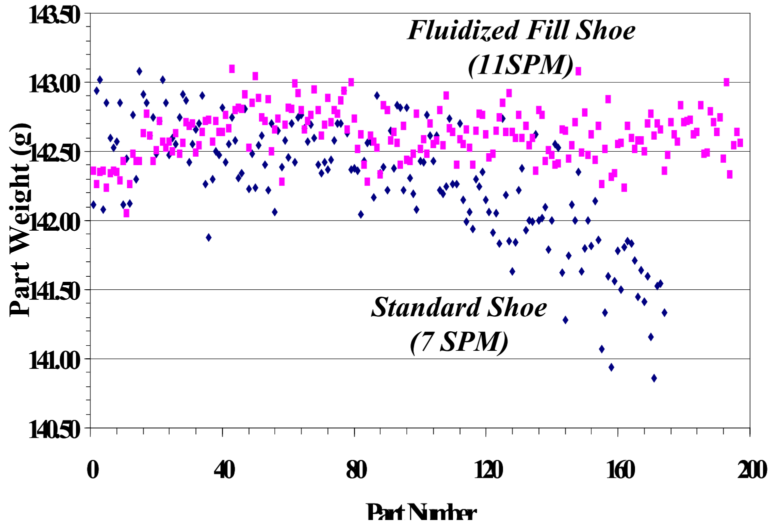
(b) Weight control for poorly-flowable iron alloy

Figure 5. The use of the fluidized fill shoe improves weight consistency for thin-wall bushing.

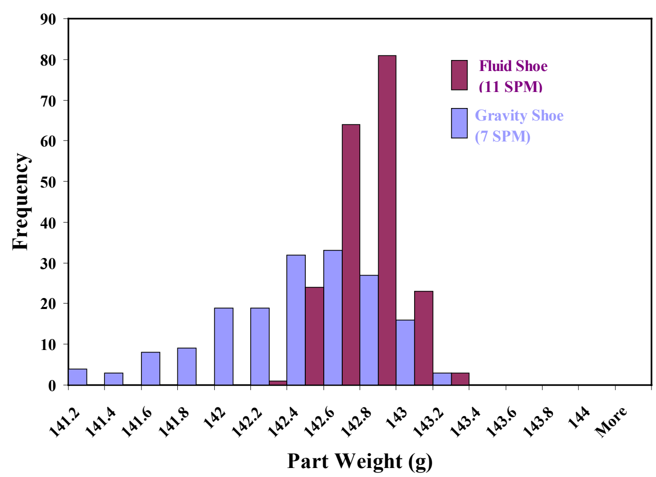
Two-Level Sprocket Gear

The second part tested was a two-level sprocket gear. The gear has a 76.2mm (3in) OD and 38.1mm (1.5in) thickness. The fluidized fill shoe was mounted on a 220T press. Parts were made first using the standard gravity fill shoe and then the fluidized fill shoe. Green parts were weighed sequentially and the results are summarized in Figure 6.

Using the standard gravity fill shoe, parts could be pressed at a maximum speed of 7SPM, while remaining within part specifications. Using the fluidized fill shoe, the production speed was increased from 7SPM to 11 SPM, a 57% increase in parts production rate, while significantly reducing weight variation.



(a) Variation in part weight using gravity fill shoe and fluidized fill shoe



(b) Weight distribution

Figure 6. The use of the fluidized fill shoe improves weight control while increasing production rate by over 50%.

Summary

Dry gas introduced at the appropriate pressure and flow rate can be used to lubricate the powder particles and greatly minimize the inconsistency and non-uniformity in powder flow rate. As such, fluidization can be used to increase and control powder flow rate, and thus give the user additional measure of control for die filling. The fluidized fill shoe provides the user with the ability to control powder flow, isolate the die filling operation from variations in powder head in the powder hose and main hopper, and greatly improve final part quality. In addition, the fluidized fill shoe provides the capability for repeated and consistent performance and, as a result, helps to reduce the influence of the user and small variations in powder characteristics from lot to lot and bring the process under tighter control.

The results for the thin-wall bushing and the two-level sprocket gear indicate that it is possible to take advantage of fluidization to increase the powder flow rates and improve the uniformity in die fill conditions to produce high quality net shape parts. It is also possible to capitalize on the increase in powder flow rates to increase production rates while maintaining high quality production.

Future Work

Further work is planned to characterize the performance of the fluidized fill shoe with regard to front to back density variations, and for large size parts.

Acknowledgement

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