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Fluidized Fill Shoe for Uniform Die Filling

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Abstract

In dry compaction of metal powders, uniform fill of die cavities is critical for net-shape production of high quality P/M parts using the conventional press and sinter approach. A fluidized fill shoe has been developed to increase powder flow rates and improve the uniformity of fill for complex-shaped die cavities. The new technology uses gas to "lubricate" powder particles, eliminate interparticle friction and improve powder flow rates. A fluidized fill shoe with a custom design delivery chute enables the delivery of powder in a fluidized state to the die cavity. This system enables the user to control powder delivery and greatly improve dimensional control.

Introduction

Powder compaction technology has made great strides over the decades. The continued demand for improved compact quality has led to constant enhancement throughout the entire process. Many experiments and studies have led to a better understanding of this process. This understanding has led to improved process equipment and materials, allowing compacts to be made cost-effectively with far superior quality than in the recent past.

One area where further improvements can be made is in the delivery of the powder to the die cavity. Two 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 front-to-back density variations. Progress in these areas will result in improvements in dimensional control.

A fluidized fill shoe powder delivery 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 (1, 2) and particles are easy to move. A schematic of the system is illustrated in Figure 1. The fluidized fill shoe uses a dry gas, such as air or argon, to "coat" particles and separate them, thereby greatly reducing interparticle friction and increasing powder flow rates. The gas provides a transport mechanism reducing interparticle friction and thereby reducing the need for bulk lubricants in the powder blend.

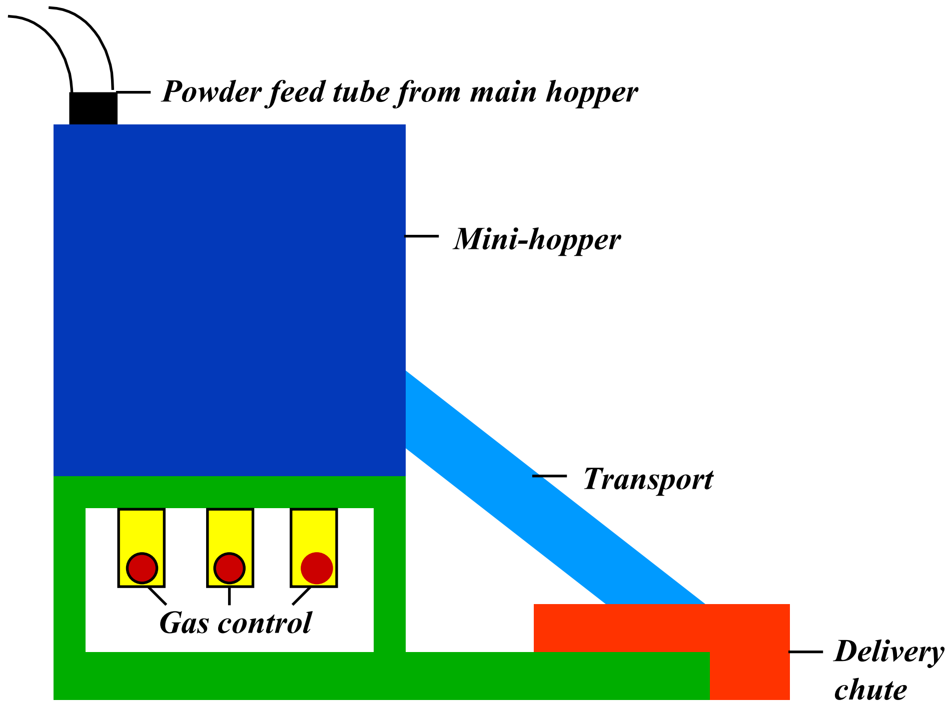


Figure 1. Schematic of fluidized fill shoe system.

The fluidized fill shoe powder delivery system has four main components:

1. **Mini-hopper.** The mini-hopper is the intermediate storage unit for powder and receives powder from the main hopper. The mini-hopper provides a break from the main hopper and thus isolates the fill shoe system from the effects of head pressure, clumping and surge, which can cause problems in gravity feed systems.

2. **Transport.** The transport provides the connection between the mini-hopper and the delivery chute.

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. An in-line dessicant container removes moisture from the gas supply. The gas control consists of three independent pressure regulators, located in a separate housing, and three pneumatic solenoids which are used to regulate the flow of gas to each segment independently. The solenoids are timed to control fluidization of the powder over the die cavity.

The powder is fluidized in each chamber independently, namely, the mini-hopper, the transport and the delivery chute. Some customization of the delivery chute may be required to optimize fill performance for individual parts or family of parts, depending on part size and shape complexity.

Powder Flow Rate Verification

To demonstrate the applicability of this system to improve powder delivery, flow rate measurements were made for five different powders. 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. Flow rates were measured for five different powders using first a Hall flow meter, then the fluidized flow meter. The results are summarized in Table I.

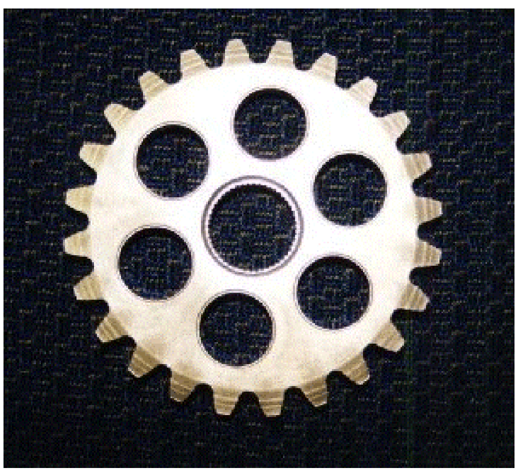
Table I. Flow time for five different powders (50g each) under gravity and fluidized conditions.

Powder Type	*Hall Flow Meter*	*Fluidized 1psi*	*Flow Meter 2psi*	*Improvement 1psi*	*Improvement 2psi*
FN-0208	*31s*	*20s*	*18s*	*35%*	*42%*
F-0000 w/0.75% lub.	*32s*	*22s*	*20s*	*31%*	*37%*
Fe-0.45 P	*30s*	*20s*	*19s*	*33%*	*37%*
90-10 Bronze	*38s*	*17s*	*15s*	*55%*	*60%*
Bronze w/3% graphite	*no flow*	*19s*	*17s*	-	-

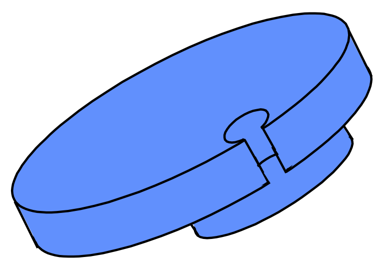
At low gas pressure, the time for 50g of powder to flow through a Hall flow meter is reduced by 31 to 55% depending on the powder characteristics. In addition, fluidization enables flow for bronze w/3% graphite, which does not flow through a Hall flow meter, at flow rates comparable to those of flowable powders. The gas acts as a lubricant to minimize interparticle friction which results in increased flow rates. The flow rates can be further improved by increasing the gas pressure. However, depending on powder characteristics and blend, further increase in gas pressure may or may not be desirable since it can lead to powder segregation. 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 flat. The dry gas greatly reduces interparticle friction and increases flow rates.

Parts Production Verification

Two applications of the fluidized fill shoe are discussed: a spur gear and an asymmetric disk, illustrated in Figure 2.



(a) Spur gear

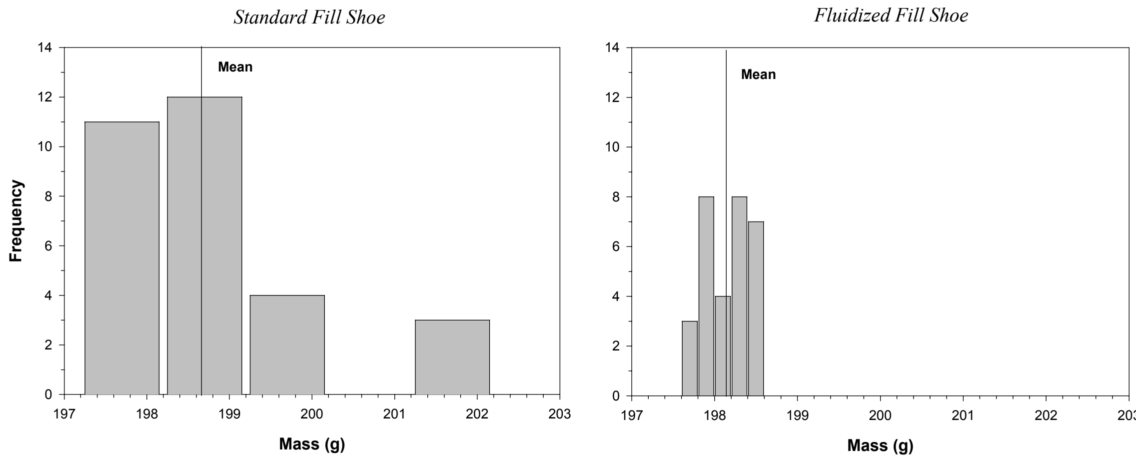


(b) Asymmetric disk

Figure 2. Parts used to demonstrate the applicability of the fluidized fill shoe.

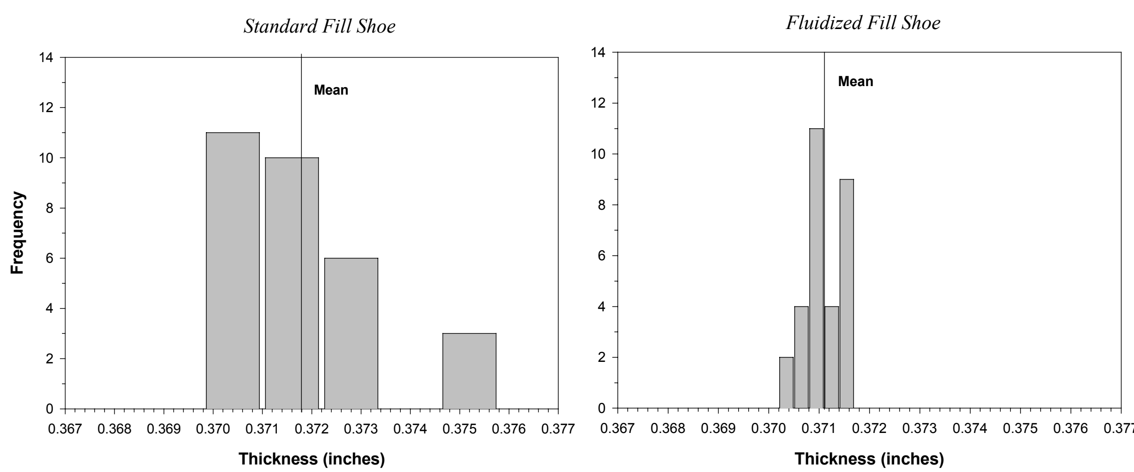
<u>Spur Gear</u>

The spur gear has an 82mm (3.23in) OD, an 18mm (0.71in.) ID and six lightening holes. This gear is made using Fe-Cu-C alloy system. The fluidized fill shoe was installed on a 200T press. First 800 parts were made at the regular production rate using the fluidized fill shoe. Parts were then made using the standard gravity fill shoe. Subsequently, all parts were sintered simultaneously under the same conditions and weight and dimensional measurements were made on the sintered parts. The results are illustrated in Figure 3 for weight and thickness variation.



Mean (M)	***= 198.6187 g***	***198.1710 g***
Standard Deviation (σ)	***= 1.2578 g***	***0.3079 g***
(3 x σ) / M	***= 1.8998 %***	***0.4661 %***

(a) Weight control



Mean (M)	***= 0.3718 in.***	***0.3711 in.***
Standard Deviation (σ)	***= 0.0016 in.***	***0.0004 in.***
(3 x σ) / M	***= 1.2910 %***	***0.3234 %***

(b) Thickness control

Figure 3. The use of the fluidized fill shoe improves weight and dimensional tolerance for the spur gear by a factor of four.

Weight and dimensional control. The results show a factor of four reduction in the standard deviation for both weight and thickness. The same fill depth was used with the standard fill shoe and the fluidized fill shoe. The use of the fluidized fill shoe resulted in a reduction in part weight from 198.6g to 198.2g. This corresponds to a 0.2%

reduction in part weight, which can be easily compensated with minor adjustment in fill depth.

Asymmetric Disk

The second part tested was an asymmetric disk. The disk has a 68.6mm (2.7in) OD and a 25.4 mm (1in) thickness. The fluidized fill shoe was mounted on a 220T press. Ninety parts were made at the regular production rate of 8.5 strokes per minute (SPM), first using the fluidized fill shoe and subsequently using the standard gravity fill shoe. Measurements were then made on green parts.

Weight and dimensional control. The standard deviation on part weight was reduced from 0.77g using the standard gravity fill shoe to 0.34g using the fluidized fill shoe. The same fill depth was used with the standard fill shoe and the fluidized fill shoe. The use of the fluidized fill shoe resulted in a reduction in part weight from 318.2g to 317.8g. This corresponds to a 0.13% reduction in part weight, which can be easily compensated with minor adjustment in fill depth.

Production rate. To take advantage of the increase in flow rates, the press speed was increased from 8.5SPM to 11.2SPM, a 32% increase in parts production rate. Measurements on green parts showed a further reduction in part weight standard deviation to 0.24g. The average part weight was unchanged at 317.8g.

Summary

The fluidized fill shoe was designed to achieve two main objectives, namely, improve powder flow characteristics and improve final part quality by improving dimensional control. The results for the spur gear and the asymmetric disk 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. The standard deviation on weight for each part was reduced by a factor of 3 to 4. 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.

It is also possible to capitalize on the increase in powder flow rates to increase production rates while maintaining high quality production. The delivery chute can be customized to the part geometry and provides the capability to deliver powder where it is needed to achieve a uniform fill for complex-shaped die cavities. In addition, by controlling the gas pressure and timing, the amount of powder delivered to the die cavity can be regulated to meet part requirements and press speed. Further, fluidization can be used to improve flowability of powders with poor flow characteristics.

In summary, the fluidized fill shoe adds flexibility to the conventional P/M process by providing additional control to the user and improving production rates, while meeting the requirements for fabrication of high quality, net shape parts.

Future Work

Further work is planned to characterize the performance of the fluidized fill shoe with regard to front to back density variations, for powders without added lubricants and for powders with very poor flow properties.

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