PRESSING CHALLENGING PARTS ON A PRODUCTION SCALE BY USING DIE WALL LUBRICATION TECHNOLOGY

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ABSTRACT

Recent developments have made the use of the die wall technology, an efficient and reliable way of pressing parts, of complex shapes and high aspect ratio, even at high densities. The goal of this paper is to review recent improvements and concerns of the industry regarding this technology to press complex parts. The impact of using this technology on the properties of typical P/M parts, such as green density, density gradients, and ejection behavior is discussed.

INTRODUCTION

Steel P/M parts with high static and dynamic properties are required to compete against their machined, cast or forged counterparts in highly stressed applications. It is well known that sintered properties of P/M steels can be improved by alloying, liquid phase sintering, high temperature sintering and heat treatments. Nevertheless, the density remained of the key parameter controlling the sintered properties, especially the dynamic properties, such as fatigue properties or impact strength. Various compaction methods are available to the P/M industry to produce high green density components. Warm compaction (WP), double press-double sinter (DPDS), die wall lubrication (DWL) and powder forging (P/F) are the most established techniques known to increase green density with respect to conventional pressing (CP). Figure 1 summarizes the performance to cost ratio that can be expected from these different techniques.

As can be seen on the Figure 1, among all the techniques increasing the density of green components, warm compaction and die wall lubrication have the highest performance to cost ratio. The cost effectiveness of the die wall technology depends mostly on its impact on part production speed. The speed of presses equipped with a die wall unit is usually lowered by the die wall lubrication operation. For simple parts where the production rate of conventional pressing is high, the die wall technology is not competitive. However for complex parts that cannot be pressed conventionally or where the production rate of conventional pressing is limited, cost saving related to the reduction in admixed lubricant and furnace operation (gas and maintenance) can lower the total cost of the die wall technology, which could be under that of conventional pressing.

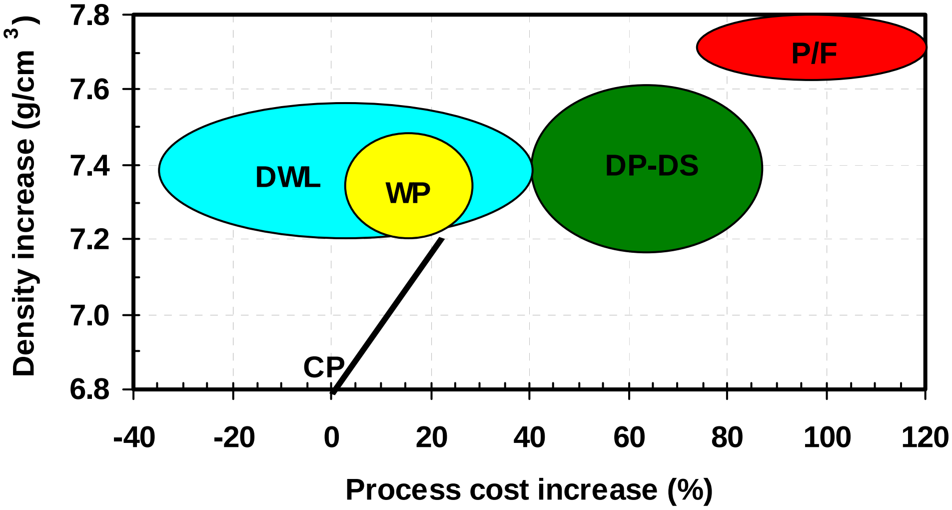

Figure 1: Cost to performance ratio as respect to conventional pressing of regular mixes [1].

In addition to productivity, several other concerns have yet to be addressed so the die wall lubrication technology (DWL) can be considered as a reliable manufacturing method for mass production. The advantages and main concerns expressed by manufacturers regarding this process are summarized on table 1.

Table 1: Advantages and key concerns of the industry regarding Die Wall Lubrication Technology

Advantages	Concerns
❖ High green densities ❖ Lower density gradients ❖ Long aspect ratios ❖ Less admixed lubricant ▪ Less lubricant burn-off ▪ Better flow rates ▪ Cost effective mix	❖ New technology⇒ Training, Know-how ❖ Part complexity⇒ Uniformity of the lubricant coating ❖ Part production speed ❖ Stability and tooling safety ❖ Process capability

An improved die wall lubrication approach has been developed to address and overcome the concerns regarding this technology. This approach led to the recent commercialization of a robust die wall lubrication system [2].

In this paper, the basic principles of the improved die wall lubrication approach are first described. More detailed description can be found in the literature [3, 4]. It is then shown that challenging powder formulations containing no or low internal lubricant and no or low graphite can be compacted at high densities by using the improved DWL system. The improvements of the green properties and ejection performance are illustrated with respect to conventional compaction of regular mixes. Stability and safety concerns are also addressed. Finally, possible optimization of the DWL system with respect to production rate and press stroke is reviewed in the last part of the paper.

PRINCIPLES OF IMPROVED DIE WALL LUBRICATION SYSTEM.

As other P/M die wall lubrication systems, the concept of the improved DWL system is based on the spraying of a tribocharged lubricant into the die cavity. However, this DWL system is equipped with a spraying unit that has been designed to improve the deposition of the lubricant on the die walls and also to prevent the occurrence of lubricant dust outside the die cavity. This system is particularly useful for long die-fill cavity or complex parts.

As shown in Figure 2, the die wall lubrication system consists in two major features: a dosing unit for measuring and delivering a precise and adjustable quantity of dry lubricant and a spraying unit that can be located in front of the feed shoe. As discussed in the last part of this paper, the spraying unit could also be activated independently from the feed shoe of the press.

- The dosing unit measures the exact amount of lubricant from a feed hopper and transfers it into the spraying chamber. The lubricant is then propelled by a controlled pressure and volume of dry gas and transferred to the injection holes of the confining block. Lubricant particles are tribocharged due to their rubbing against the surface of the hoses.
- The spraying unit consists in a confining block and a die cover plate. The confining block is made of a polymer part containing several strategically positioned injection holes. The polymer part has geometry similar but slightly smaller than the die. An actuator introduces the confining block into the die before the filling operation. When positioned for injection (see Figure 2), the confining block enables to spray the lubricant near the die walls to maximize the attraction forces between charged lubricant particles and die walls, and to force the lubricant deposition in difficult areas such as corners or sharp and deep edges. To limit turbulence in the cavity during the injection step, exhaust vents located in the die cover plate, that obstructs the die aperture, enable the excess of lubricant to exit the die cavity, where it is collected by a dust collector system. If necessary, the dosing unit is able to deliver specific amounts of lubricant to each injection hole in the confining block.

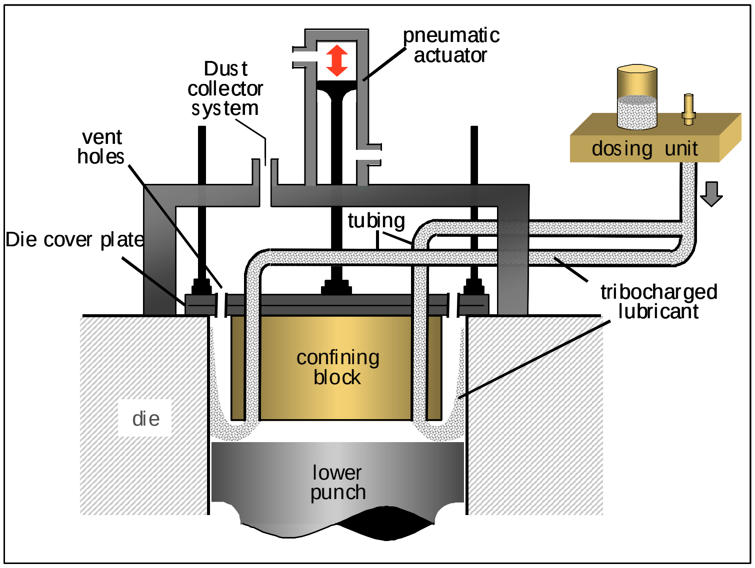

Figure 2: Schematic diagram of the die wall lubrication system.

EXPERIMENTAL CONDITIONS

Materials used and parts produced

Three different powder materials were prepared for that paper. The first material is ATOMET EM-1, an iron-resin used for soft magnetic applications. This powder contains no graphite and internal lubricant. It was processed by the die wall technology. The second material and third material are made of ATOMET 1001HP admixed with 0.25% graphite. Mix 2 contains 0.20% internal lubricant and Mix 3, 0.75% internal lubricant. Mix 2 was processed by the die wall lubrication technique while Mix 3 was conventionally pressed without the use of an external die wall lubricant.

Izod bars and two types of gears (G#1 and G#2) were compacted on an industrial 150 tons Gasbarre mechanical press using the DWL system and tool steel dies. These parts have aspect ratios ranging from 2.3 to 13.8 as described in Table 2. The geometry of the two gears is shown in Figure 3. Izod bars and gears G#1 were compacted with Mix 1. Gears G#2 were compacted with Mix 2. Results were compared to those of a Mix 3 compacted without DWL. Parts were pressed at pressures ranging from 550 MPa (40 tsi) to 950 MPa (68 tsi) and at a production rate of 5 parts per minute.

Table 2: Experimental conditions used for production scale results reported in the paper.

Mix ID	Based powder	Graphite (%)	Internal lubricant (%)	Part	Height (mm/in)	Aspect ratio M/Q*	Pressing condition
Mix 1	ATOMET EM-1	0	0	Izod bar	12.7/0.5	2.3	DWL
				G #1	12.7/0.5 16.5/0.65	3.6 4.7	DWL
Mix 2	ATOMET 1001HP	0.25	0.2	G #2	28/1.1	13.8	DWL
Mix 3	ATOMET 1001HP	0.25	0.75	G #2	28/1.1	13.8	CP**

* The aspect ratio M/Q is defined as the ratio of the wall friction area to the compacting area [5]; for instance, M/Q= 1.4 for a standard 6.35 mm (¼") TRS bar.
** CP: conventional pressing.

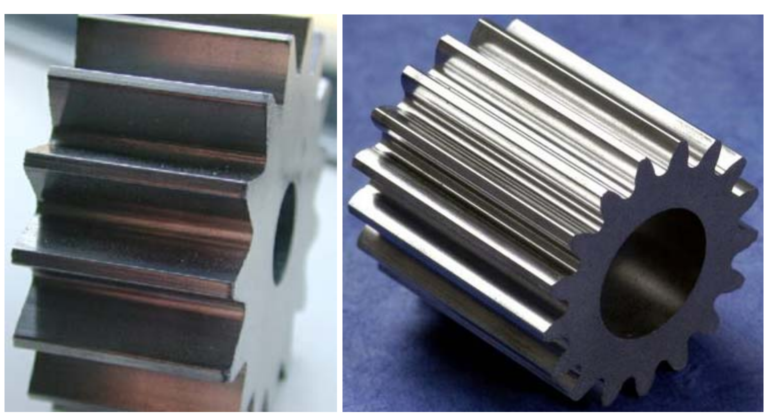

Figure 3: Pictures of gears #1 (left) and gears #2 (right) pressed in that sutdy.

DWL spraying conditions

The spraying unit was fixed in front of the feed shoe of the press. For the gears, spraying units were designed to lubricate both the die walls and the core rod. Figure 4 shows a schematic drawing of the confining block and die cover plate used for pressing gears #1. The core rod and the die walls were coated independently by injecting the lubricants in two different chambers (zone A and zone B). The injection holes and exhaust vents in the confining block and die cover plate were specifically positioned to ensure a preferential and oriented path of lubricant. The spraying parameters, i.e. the lubricant quantity sprayed, the spray duration, as well as the pressure of the flowing gas were adjusted to optimize the uniformity of the lubricant applied on the die walls.

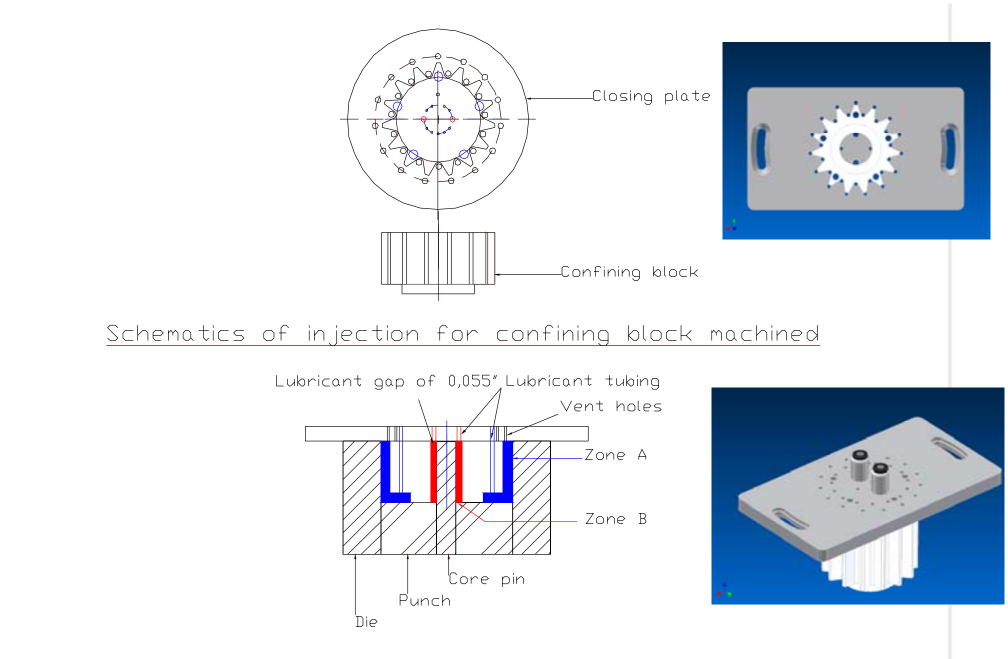

Figure 4: Drawing of the spraying unit (confining block and closing plate) used to apply lubricant both on die walls and core pin when processing gears #1.

RESULTS

Choice of DWL lubricants

Conventional P/M lubricants can be most of the time used as external lubricants to press simple parts with the die wall technology. However, for complex parts or challenging powder formulations having low level of internal lubricant and graphite, optimization and/or development of new DWL lubricants might be required to fully benefit from this technology. For instance, Figure 5 shows the effect of different DWL lubricants on the ejection performance of Mix 2 containing low quantity of graphite during compaction tests of gears G#2 at a fixed density.

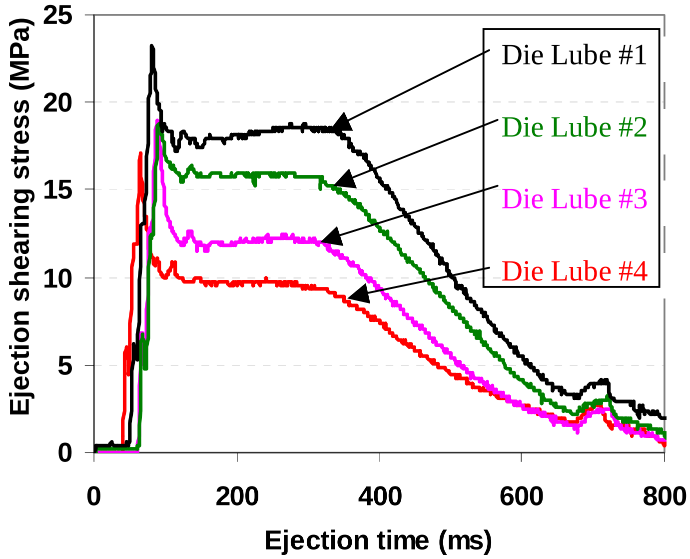

Figure 5: Effect of DWL lubricants ("Die Lubes" #1 to #4) on the ejection performance of Mix 2 (gears #2) compacted at a fixed density.

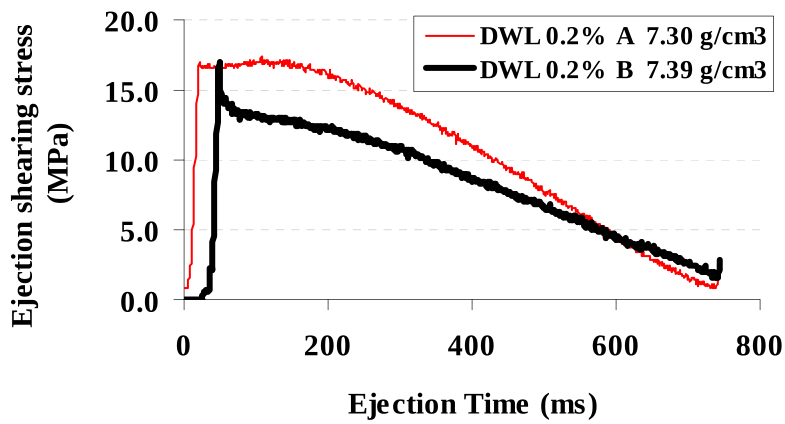

Figure 6: Ejection curves of Mix 2 compacted with two different admixed lubricants (0.2% lubricant A or 0.2% lubricant B). Compacting pressure was 827 MPa (60 tsi) and die wall lubricant was Die Lube #2.

The efficiency of the die wall lubrication technology is also affected by the type of lubricant admixed to the mix. For instance, Figure 6 shows that for a given die wall lubricant, different types of admixed lubricant affect significantly the ejection performance and green density of Mix 2.

The results shown in figure 5 and 6, clearly indicate that proper combination of external and internal lubricants is key to maximize both green density and ejection performances. In this study, Die Lube #4 was the best external lubricant for processing gears G#2 with Mix 2 while Die Lube #2 was the optimum external lubricant to press gears G#1 and IZOD bars with Mix 1.

Green properties and ejection performance

Table 3 summarizes the green properties and ejection performances of the all the mixes evaluated. Regarding EM-1, these results show that the use of DWL with adequate external lubricant and spraying conditions enables:

- To press to densities above 97.0% of the pore free density or ~ 7.40 g/cm³ even if the mix contains no graphite and no internal lubricant.
- To maintain excellent ejection performances even when increasing the aspect ratio and the compacting pressure, see Figure 7 and Table 3).

Table 3: Green densities and stripping pressures obtained with the different production scale pressing conditions studied.

Mix	**Parts produced**			**Shaping conditions**		**Results**	
Mix	**Part**	**Height (in)**	**Aspect ratio M/Q**	**Compacting Pressures MPa (tsi)**	**DWL**	**Green Density (g/cm^3)**	**Stripping pressure MPa (tsi)**
Mix 1	Izod bar	0.5	2.3	660 (48)	Die Lube#2	7.20	21-22 (1.5-1.6)
	Gear #1	0.5	3.6	660-960 (48-50)	Die Lube#2	7.20	19-21 (1.4-1.5)
		0.65	4.7	938 (68)	Die Lube#2	7.40	21-22 (1.5-1.6)
Mix 2	Gear #2	1.1	13.8	538 (39)	Die Lube#4	7.09	16-17 (1.2)
				900 (65)	Die Lube#4	7.40	16-17 (1.2)
Mix 3	Gear #2	1.1	13.8	538 (39)	No DWL	7.04	16-17 (1.2)
				830 (60)	No DWL	7.24	19-20 (1.4)

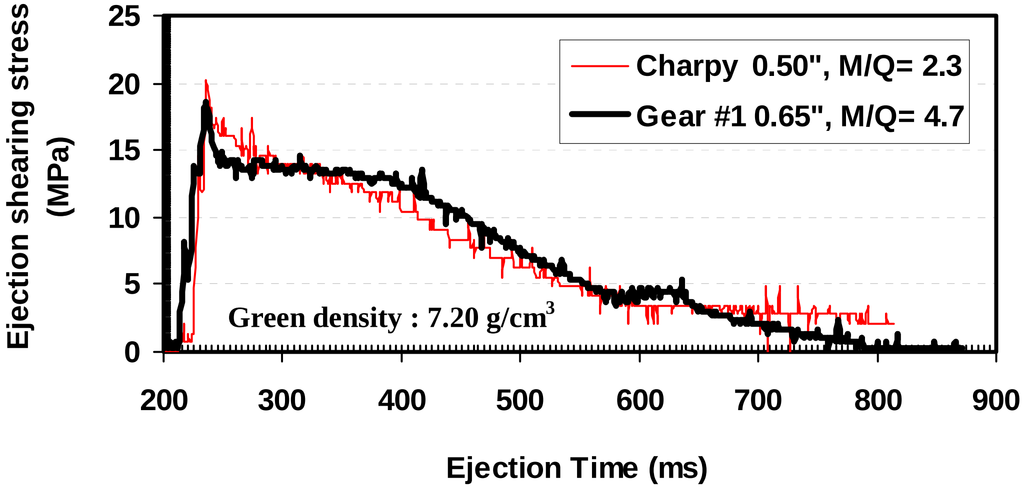

Figure 7: Effect of aspect ratio on the ejection performance of Mix 1 compacted with DWL

When compacting complex parts at high pressures such as gear G#2 having a high aspect ratio (M/Q = 13.8), the benefits of using die wall lubrication vs. conventional pressing are significant, both in terms of green density (Figure 8) and ejection performance (Figure 9). The higher densification observed with Mix 2 can be explained both by the excellent lubrication at die walls and by the lower amount of internal lubricant, that postpone the occurrence of inhibition of compaction at high pressures due to the volume of lubricant entrapped in the porosity.

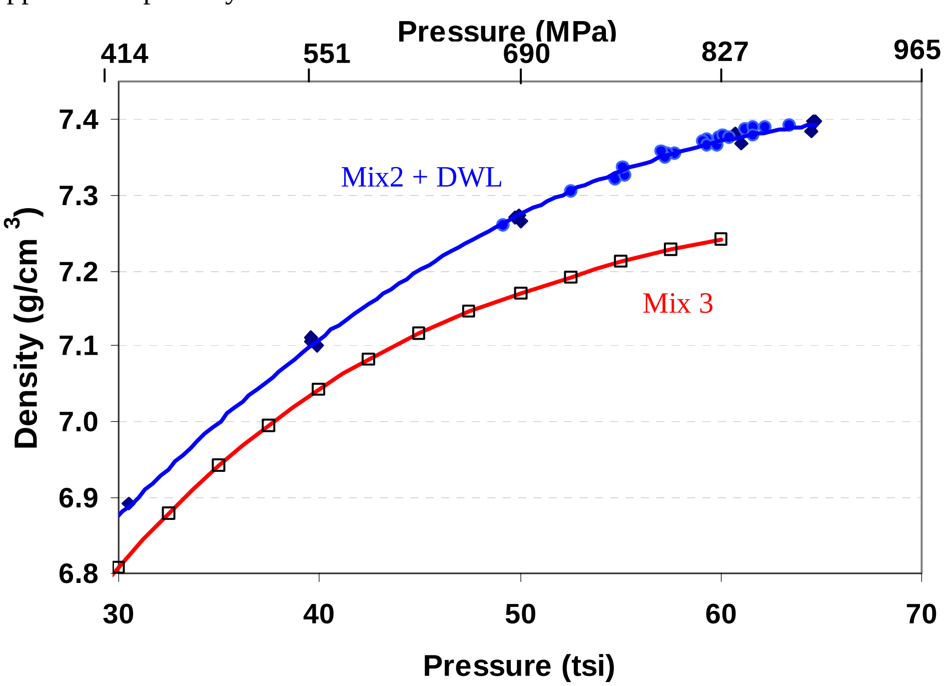

Figure 8: Compressibility curve of Mix 2 compacted with DWL as compared to the reference mix, Mix 3

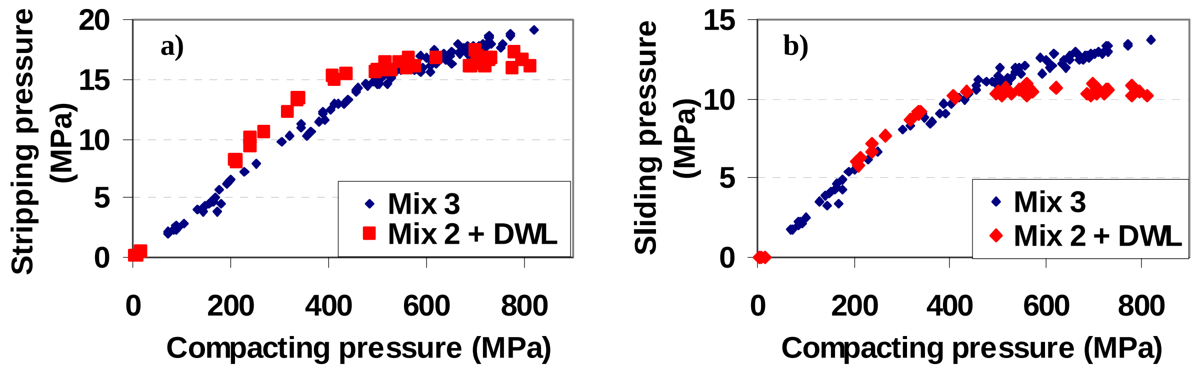

Figure 9: Ejection performance of Mix 2 compacted with DWL vs. the reference mix, Mix 3 (conventional pressing): a) stripping pressure, b) sliding pressure

When adequate external lubricant and spraying conditions are used, Figure 9 shows that for Mix 2, the stripping and sliding ejection pressures tend to stabilize at compacting pressures higher than 550 MPa (40 tsi), respectively at 16.5 MPa (1.2 tsi) and 10.3 MPa (0.75 tsi), while they continue to increase with the reference Mix 3, reaching respectively 19.3 MPa (1.4 tsi) and 13.8 MPa (1.0 tsi) at 827 MPa (60 tsi). These results show the efficiency of the improved DWL system that enables to maintain low friction at die walls at high compacting pressures, even though the aspect ratio of the parts compacted are quite high (~10 times higher than a standard 6.35 mm (¼") TRS bar). The use of DWL with toolings that can sustain high compacting pressures (up to 1000-1200 MPa) could therefore be very interesting to produce high density parts while maintaining ejection performance at the same level that conventional pressing at usual compacting conditions.

Figure 10 shows the benefits of using the DWL technology by comparing the density gradients in the high aspect ratio gear G#2 (height of 28 mm) compacted at 540 MPa (39 tsi) and 900 MPa (65 tsi) with the die wall mix (Mix 2) and the regular mix (Mix 3). Density gradients were evaluated by measuring the density of 3 mm thick slices cut at the top, middle and bottom of the gears.

As already shown in previous studies [6], density gradients of parts pressed with the die wall lubrication technology are significantly reduced. In this study, gears pressed at 540 MPa (39 tsi) with DWL had a maximum axial density variation of 0.23 g/cm^3 compared to 0.43 g/cm^3 for the gears produced by conventional pressing at the same pressure. For compacting pressures of 900 MPa (65 tsi), the maximum axial density variation of the gears pressed with DWL falls to 0.02 g/cm^3. At this high compacting pressure, lower density variations could also be expected for the gears pressed by conventional pressing. However, unlike conventional pressing, the die wall lubrication process allows the application of higher compacting pressures while maintaining adequate ejection pressures and, at

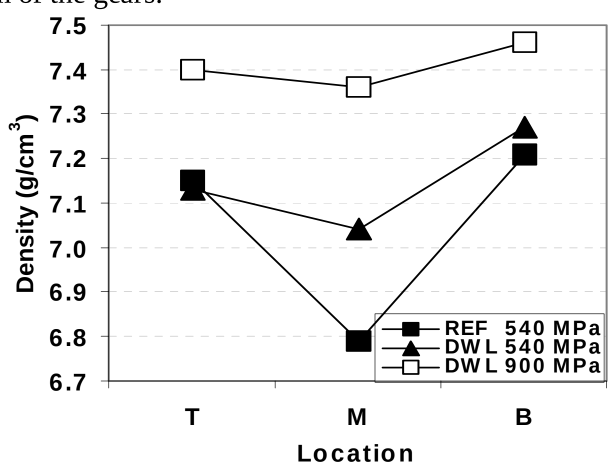

Figure 10: Axial density variation of gears #2 pressed at different compacting pressures with and without die wall lubrication technique.

the same time, limits delamination due to spring-back. The improvements in density variation can be explained by the fact that the pressure loss along the height of parts pressed with the die wall process is decreased due to less friction on die walls. This is particularly true for parts having a high aspect ratio as the gears G#2. In this study, for the high aspect ratio gears, the lower pressure loss decreases the axial density variation and at the same time increases the average green density of the parts at all compacting pressures.

Part to part stability and safety

As mentioned earlier, the two main concerns expressed by manufacturers regarding the DWL technology is the part-to-part stability and safety during production runs. This section addresses these two concerns and highlights different approaches taken to ensure maximum safety of the DWL assisted compaction process.

Monitoring of part-to-part ejection pressures is the best method to assess the stability of the DWL assisted compaction process. Figure 11 is an example of the part-to-part ejection stability recorded during the compaction of 600 parts (gears G#1) of Mix 1 to a fixed density of 7.20 g/cm^3. The ejection performance is stable as reflected by the low part-to part variation of the stripping and sliding pressures. In addition, it can be seen that the slight increase of compacting pressure at the end of the production run did not lead to an increase of the ejection pressures. This behaviour has already been described (see Figure 9) and shows that the assisted DWL compaction process is doted of a good safety factor.

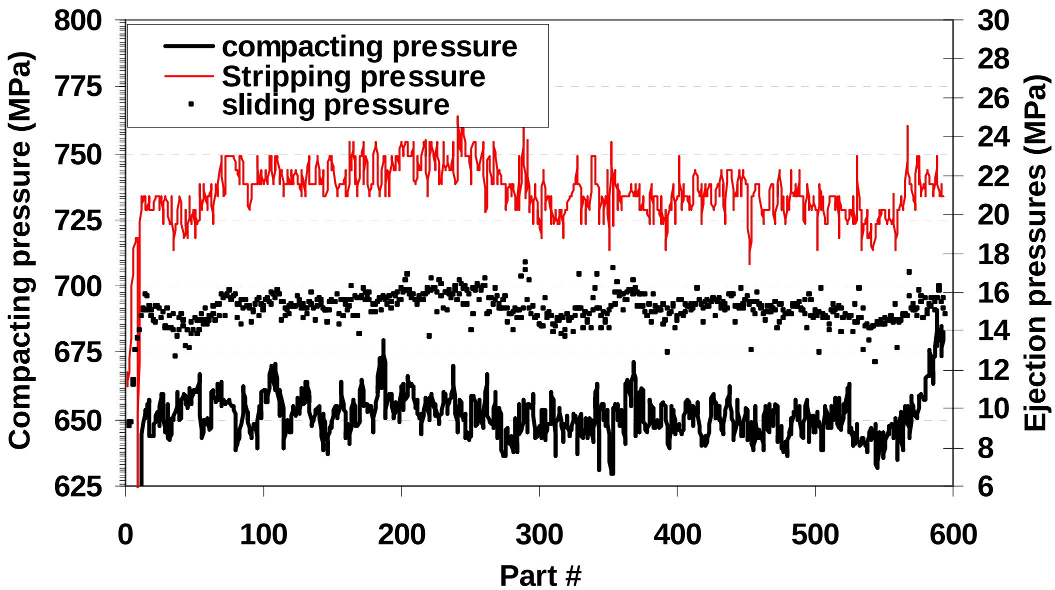

Figure 11: Part-to-part compacting pressure and ejection stability of half inch thick Izod bars pressed with Mix 1 at a density of 7.20 g/cm^3.

Safety of the system was also illustrated by the compaction of a series of 1000 gears G#2 with Mix 2. Results are shown in the Figure 12. The die wall lubrication system was intentionally stopped for the last 5 parts of the run. As can be seen, the ejection pressure remained at an acceptable level where no damage is observed. This result is important, because one of the main concerns regarding the use of the die wall lubrication compaction process on a production scale is related to the risk that the occurrence of improper die wall lubrication will cause tooling seizure.

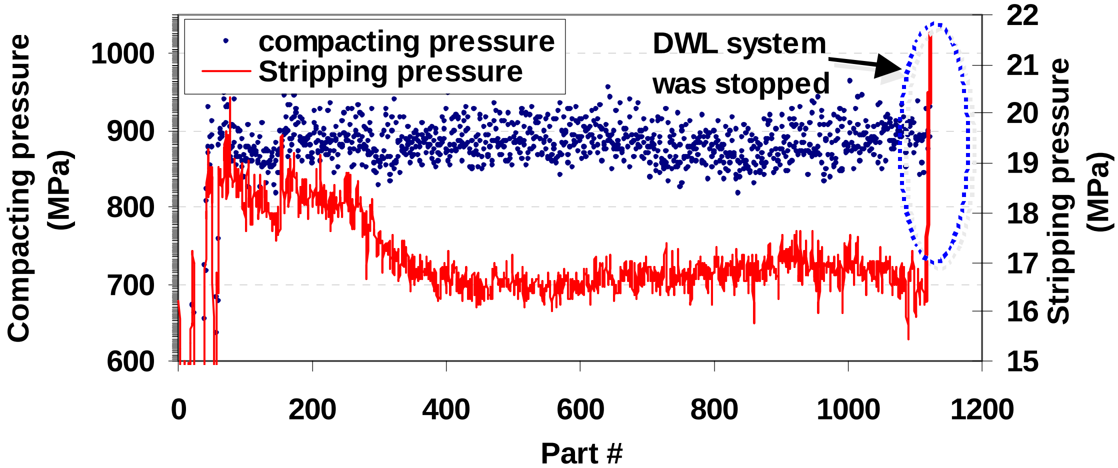

Figure 12: Part-to-part ejection pressure stability (1 part up to 50) of gear #2 pressed at 900 MPa (65 tsi) at a density of 7.4 g/cm^3.

In summary, it can be concluded that two different phenomena contribute to increase the safety of the tooling when the die wall lubrication process is used. The first one is related to the fact that, above a certain compacting pressure (typically 550 MPa (40 tsi)), the ejection pressures tend to reach a plateau and is very stable. Monitoring the ejection pressure can thus be used as a safety tool during production runs. The second one arises from the fact that after the pressing of few parts with the die walls covered with a very efficient lubricant, a certain conditioning appears and a lubricant layer remains after the ejection. Tooling is then able to sustain few compacting cycles without the need of being additionally lubricated.

In addition to the recording of the ejection pressures, other features can also be used to ensure the tooling safety. Optical detectors acknowledging lubricant spraying or tribostatic charge measurement devices are few examples. Their use allows stopping the press in the case of an inadequate lubrication operation before pressing. Optical and strain gage monitoring devices are currently available on the commercial die wall lubrication machine [2].

<u>OPTIMIZATION AND IMPROVEMENT OF THE DWL SYSTEM</u>

The concerns regarding the stability of the die wall technology and the safety of the toolings were addressed in the previous section of this paper. In this last section, approaches to answer questions regarding production rate, required press stroke and shoe control when using the die wall technology is discussed.

Shoe control

For spraying units attached in front of the feed shoe, the use of the die wall technology requires a close control of the shoe. The following parameters must be considered:

- Velocity: Should be easily adjusted

- Motion control: Should be flexible
- Maximum displacement: Should allow enough space to accommodate the spraying unit
- Precision and consistent positioning of the shoe: Should allow the proper positioning of the confining block in the die.

Press stroke

For spraying units attached in front of the feed shoe, the press stroke must be large enough to accommodate the spraying unit of the DWL system.

Production rate

The pressing cycle time is increased by the die wall lubrication operation. As a first approximation, the total cycle pressing is increased by 2 seconds. The coating operation requires 1 sec (including time to fire up and down of the confining block). The drop fill operation requires 1 second to fire up the die plates to expose the die walls and to fill properly the die cavity.

On going developments to improve production rate and flexibility

Figure 13 shows a DWL system reconfigured so that the spraying unit is independent of the shoe. This system can be adapted on any kind of press and does not require special features and skills to control adequately the motion of the shoe. In addition, the fact that the spraying unit is not attached in front of the feed shoe increases the production rate. Indeed, the cavity is available faster for compaction after the retrieval of the shoe. Moreover, in this configuration, the confining block actuators are horizontally positioned therefore requiring less press stroke.

The introduction of the DWL technology in the P/M industry requires simple and flexible systems. The reconfigured system, shown in Figure 13, addresses the most frequent problems that were encountered in different industrial cases. However, other configurations, addressing the same issues, are also being developed with the objective of finding the best performing DWL configuration on a case-to -case basis.

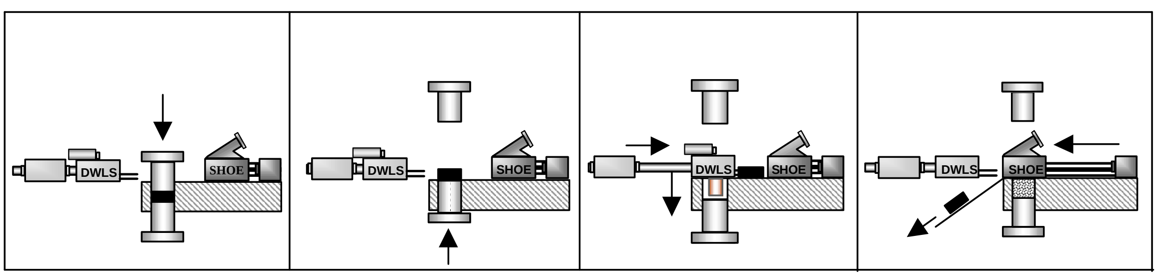

Figure 13: DWL system configuration where the spraying unit actuator is independent of the feed shoe.

CONCLUSIONS

The benefits of using the die wall lubrication compaction process to press challenging powder formulations and/or parts on a production scale were illustrated with respect to conventional pressing. The results showed that:

1) A proper combination of external and die wall lubricants can result in maximum gains in green density and ejection performances when using the DWL compaction process.
2) The use of the DWL compaction process reduces significantly the density gradients in high aspect ratio parts pressed at conventional compacting pressures (550 MPa (40 tsi)).
3) The ejection performances of mixes processed by the DWL technology are superior to those of mixes conventionally pressed at pressure beyond 40 tsi. In addition the ejection performances are maintained while increasing the aspect ratio of parts and compacting pressure.
4) The deposition of the external lubricant is consistent resulting in good part-to-part ejection stability.
5) Die conditioning by the die wall lubricant ensures a good safety factor to the DWL compaction process.
6) Optical and strain gage monitoring devices are available on the commercial die wall lubrication machine[2] to make this process 100% safe for the tooling.

In this paper most of the concerns regarding the DWL compaction process were addressed. It is clearly shown that the DWL system used in this study can be safely and efficiently used for mass production of high aspect ratio parts at a competitive cost. The DWL compaction process should be viewed as a process of choice for producing challenging high-density parts. The next step will be to determine the process capability of this technology on a production day-to-day basis.

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