



A NEW APPROACH TO DIE WALL LUBRICATION FOR P/M APPLICATIONS

by

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# **A NEW APPROACH TO DIE WALL LUBRICATION FOR P/M APPLICATIONS**

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## **ABSTRACT**

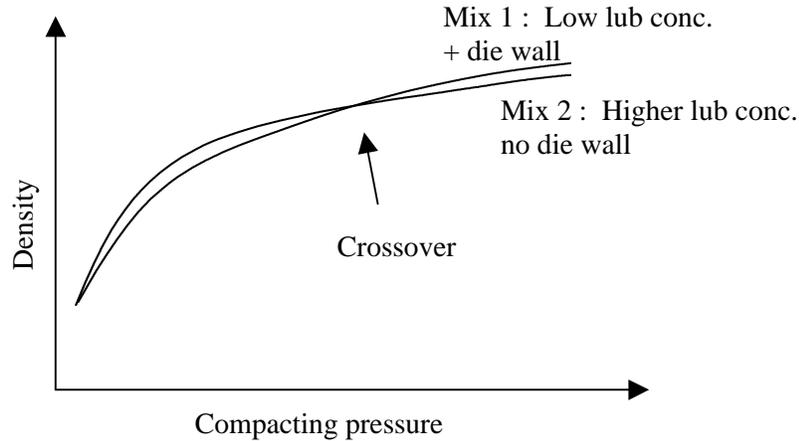
Reducing the amount of admixed lubricant is an attractive route to increase density and improve properties of P/M components while minimizing the negative effects associated with lubricant burn-off in sintering furnaces. Previous studies have shown that die wall lubrication can be used to reduce the amount of admixed lubricant needed for the compaction and ejection of P/M components. However, this technology must ensure a proper control of the deposition of the lubricant on the die walls. This paper presents a new approach to coat a lubricant on die walls, consisting in the use of a confining block located in the die cavity. An evaluation of this approach on a mechanical production press is presented. Results show the benefit of using this technique combined with warm pressing to produce a relatively thick steel gear with high density under industrial processing conditions.

## **1. INTRODUCTION**

P/M industry is constantly developing new processes to increase the green density and improve the static and dynamic properties of P/M components. Different approaches exist to raise the density of green components. The first one is to modify the compaction conditions such as the pressure, compaction rate (adiabatic pressing) or temperature. Another approach is to lubricate the die walls of the tooling in order to be able to decrease the amount of admixed lubricant, and therefore increase the compressibility of powder mixes at high pressures [1]. However, a minimum amount of admixed lubricant in the premix should nevertheless be maintained since it minimizes inter-particle friction without limiting the maximum green density reachable [2, 3]. Indeed, the admixed lubricant improves the rearrangement of particles, as well as the uniformity of densification throughout the part by ensuring a good transfer of the compacting forces during the compaction step.

Figure 1 illustrates the compressibility curves of two different mixes compacted with and without die wall lubrication. The mix compacted with die wall lubrication (mix 1) contains a lower amount of admixed lubricant compared to mix 2. Also, the mix containing a higher amount of lubricant reaches higher density at lower compacting pressure than the mix with a lower lubricant

content. However, at higher compacting pressure, when the density approaches the theoretical density of the mixes, the opposite phenomena is observed [4,5]. Thus, in terms of density, it is therefore necessary to work above the cross over point to take advantage of the die wall lubrication technique. This can be achieved by either compacting the powder at higher pressure or increasing the compaction temperature by the use of warm pressing.



**Figure 1:** Compressibility of two mixes having different internal lubricant contents.

Die wall lubrication has been the object of many studies [6, 7, 8,] but due to the complexity of this process, it has not been widely used on a production scale because of a lack in controlling the amount of lubricant and especially the thickness of the coating on the die walls. More recently, after the apparition of reliable electrostatic spray system in other industrial sectors, different die wall lubrication systems have been developed and evaluated for P/M applications [9,10,11,12]. It appears that the most promising way to lubricate complex die cavity is the use of electrostatic forces that exist between charged dry lubricant powders and the grounded die cavity [1, 2].

This paper presents a new approach to lubricate the die walls of a tooling [13]. In the first part of the paper, the concept will be described while in the second part, the stability of the die wall lubrication unit on long production runs will be evaluated. Finally, the benefit of this system combined with warm pressing will be evaluated by comparing results obtained with a FC-0208 steel powder mix containing 0.75 wt % admixed lubricant.

## **2. NEW DIE WALL LUBRICATION SYSTEM**

### **2.a Description of the die wall lubrication system**

This project was initiated with the objectives of:

- Enabling a uniform deposition of lubricant on the die walls for long die-fill cavity or complex parts;
- Reducing the amount of dusting due to over sprayed lubricant;

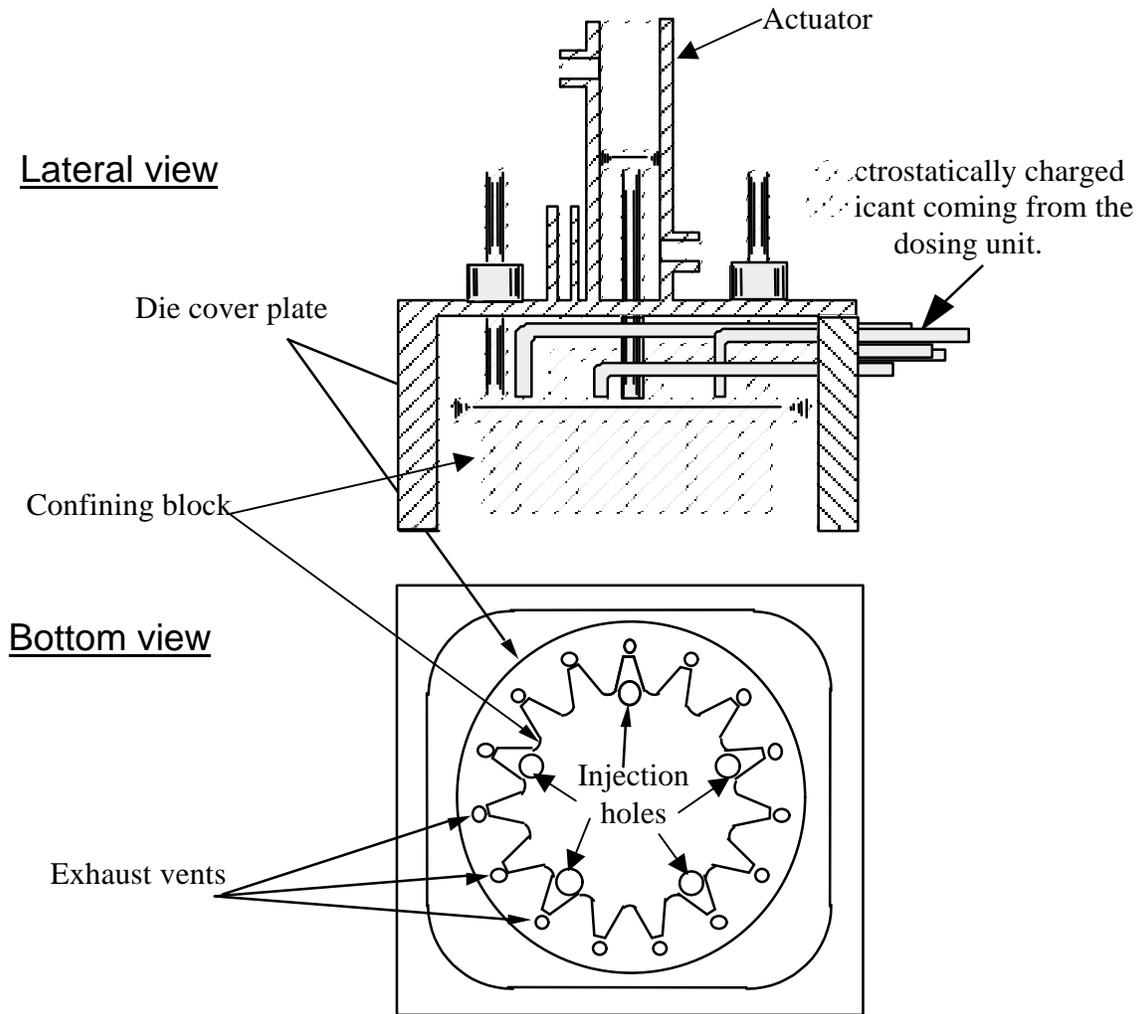
- Enabling the deposition of variable amounts of lubricant on specific intricate or demanding locations in the die cavity.

As other P/M die wall lubrication systems, the concept of lubricant deposition described in this paper is also based on the spraying of electrostatically charged lubricant into the die cavity. However, it has been proposed to use a die cover plate and a confining block to prevent the occurrence of lubricant dust outside the die cavity and in parallel to improve the deposition of the lubricant on the die walls. In fact, 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 to coat the lubricant directly on the die walls.

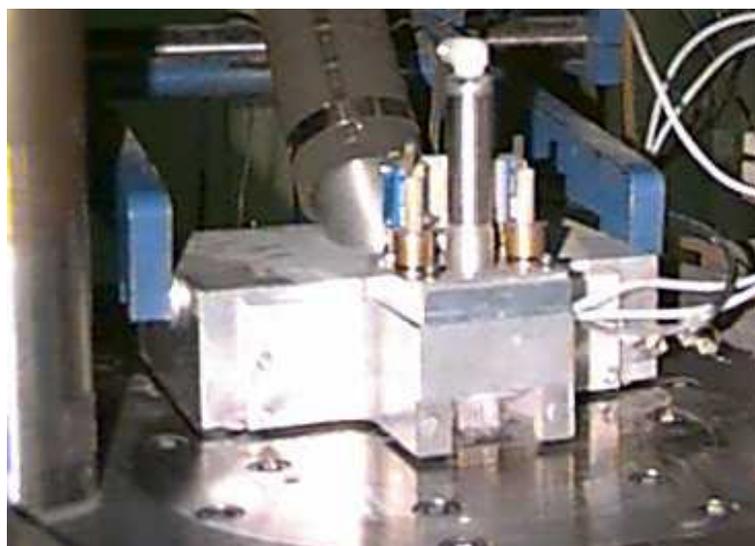
- The dosing unit measures the exact amount of lubricant from a feed hopper and transfers it into a fluidizing chamber. The lubricant is then fluidized by a controlled pressure of a dry gas and precisely transferred to the injection holes of the confining block. The lubricant particles are then electrostatically charged when rubbing against the surface of the exhaust hoses.
- The spraying unit consists in a confining block and a die cover plate. The confining block is a polymer part containing a plurality of strategically positioned injection holes. The geometry of the block is similar to that of the part with dimensions slightly smaller than those of the die, thus producing a narrow gap between the die walls and the bloc when the latter is positioned for injection. Its roles are:
  - to spray the lubricant near the die walls to maximize the attraction forces between charged lubricant particles and die walls;
  - to avoid any turbulence during the deposition;
  - to force the lubricant deposition in difficult areas such as corners or sharp and deep edges.

The die cover plate, which obstructs the die aperture during the lubricant injection process, is perforated with many exhaust vents located all along the formed gap assuring a preferential and oriented path of lubricant. The excess of lubricant is collected at the exhaust vents by a dust collection unit. Besides, if necessary, the dosing unit is capable of delivering specific amounts of lubricant to each injection hole in the confining block.

To press a specific P/M part, the confining block and the die cover plate must be designed to optimize the flow of the lubricant on the die wall. An actuator introduces the confining block into the die before filling the cavity with the powder mix. Figure 2 presents a schematic diagram of the die wall lubrication unit for the 15 teeth gear die used in this study. Figure 3 shows the system installed in front of the press feed shoe.



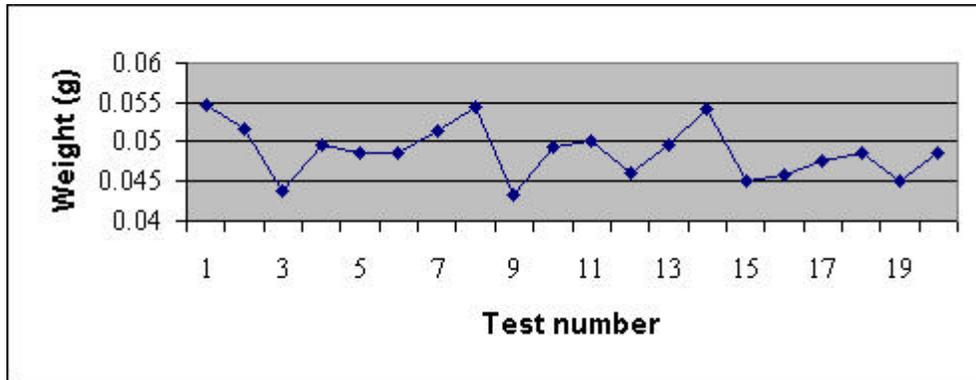
**Figure 2:** Schematic diagram of the die wall lubrication unit used for a 15 teeth gear die.



**Figure 3:** Die wall lubrication system installed in front of the feed shoe.

## 2.b Stability evaluation of the dosing unit

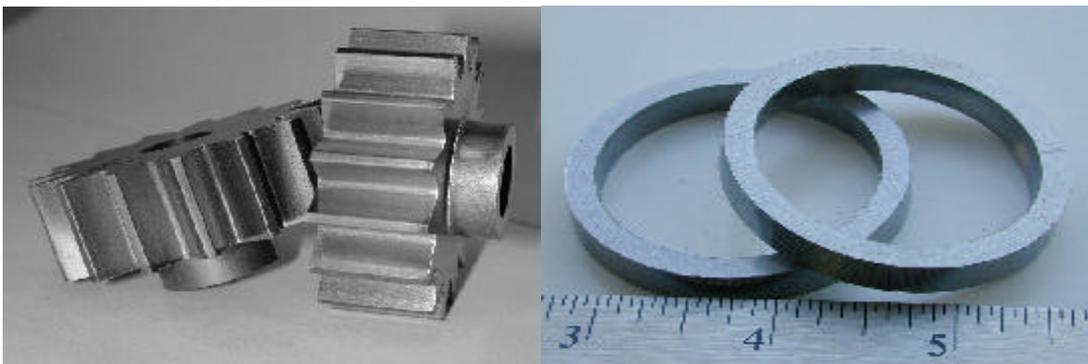
To evaluate the accuracy of the dosing unit, a series of 20 sprays was done by spraying a certain amount of lubricant for 0.3 seconds at 68.7 kPa (10 psi) directly in a vessel. After each spray, the vessel was accurately weighed. Results are presented in Figure 4. The amount of lubricant sprayed in the vessel is relatively stable from spray to spray with a standard deviation close to 7% of average weight when calculated on 20 cycles ( $\bar{x} = 0.0488\text{g}$ ,  $\sigma = 0.0034\text{g}$ ).



**Figure 4:** Lubricant weight deposited in a vessel after each spray cycle.

## 2.b Stability evaluation of the die wall lubrication system

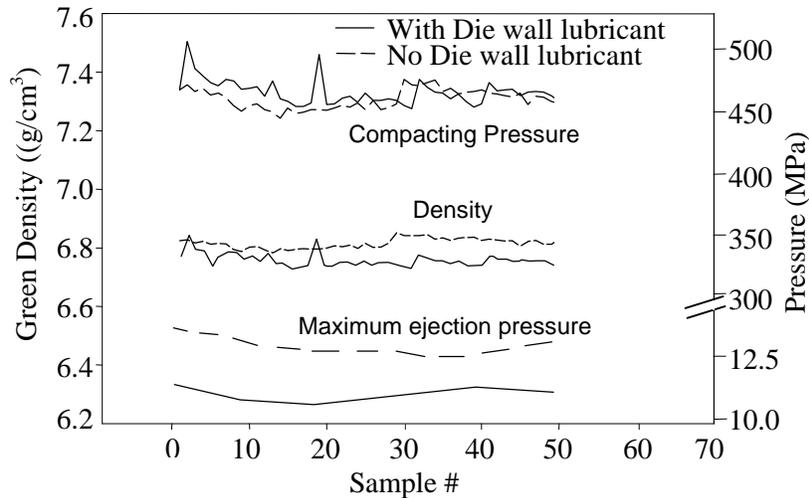
The stability of the system was evaluated using a two-level 15 teeth gear and a 6.35 mm (0.25 in.) thick ring, as shown in Figure 5. The gear has an outer diameter of 5 cm (2 in.), a core rod or inside diameter of 13 mm (0.5 in.) and a height adjusted to 1.78 cm. Its second level is 7.5 mm (11/32 in.) thick with an outside diameter of 21 mm (7/8 in.). Tests were done at room temperature, at 5 strokes per minute on a 150 ton Gasbarre industrial mechanical press.



**Figure 5:** Pictures of two-level gear parts and 6.35 mm (0.25") thick rings, used for the die wall lubrication system stability evaluation.

The stability was characterized by measuring the green densities and the compacting and ejection pressures.

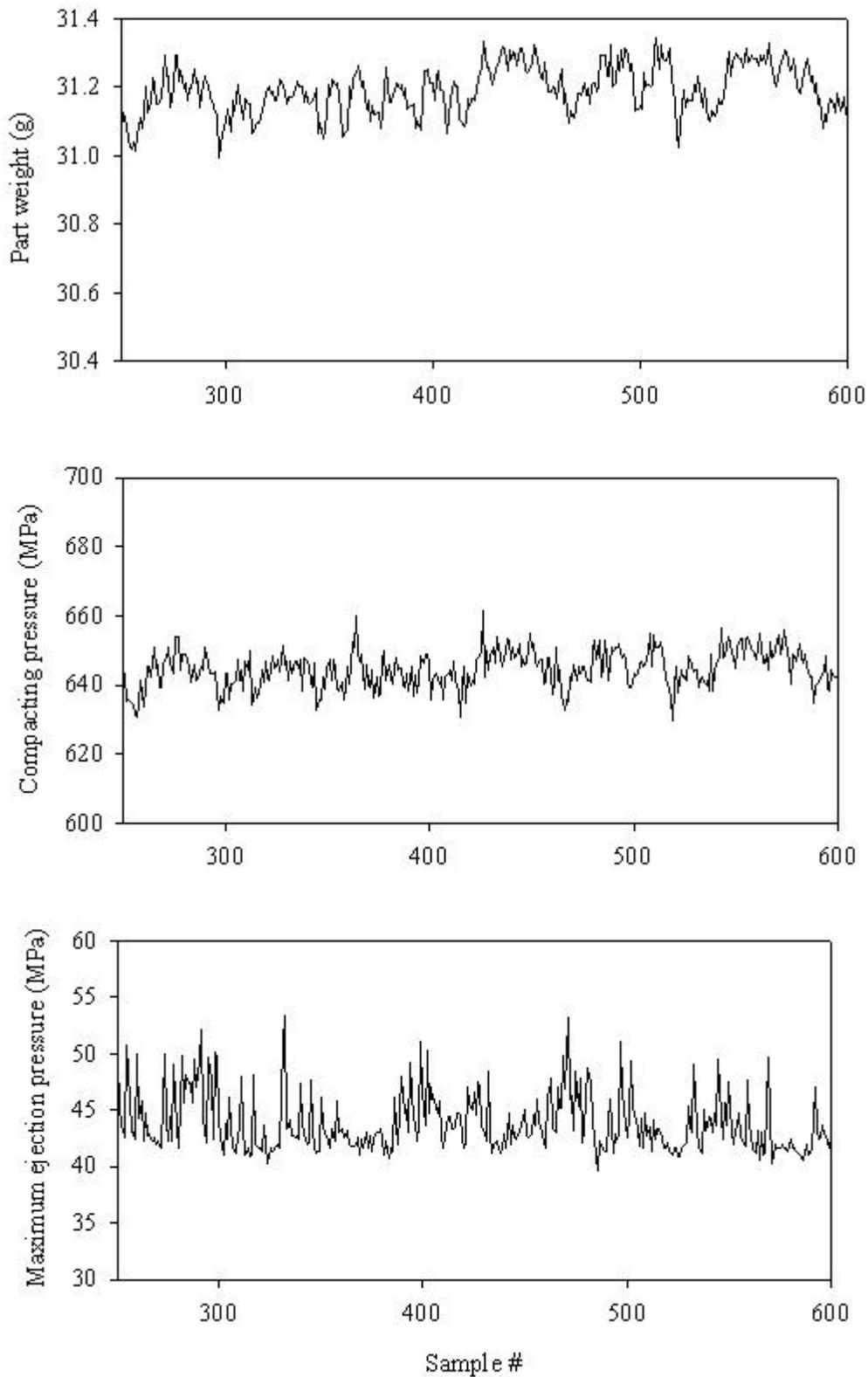
A total of 50 gears were compacted at 483 MPa (35 tsi) using F-0005 mixes with and without die wall lubrication (DWL). The reference mix used without die wall lubrication contained 0.6 wt % EBS wax as lubricant against 0.3 wt % EBS for the DWL mix. As shown in figure 6 [14], compacting and maximum ejection pressure stability as well as part to part green density variations were similar for both compaction techniques. Green densities are slightly lower for the DWL mix since cold pressing at only 483 MPa for those kind of mixes keep us working under the crossover point explained earlier. In addition, it can be noted that lower ejection pressures were obtained with the mix compacted using the die wall lubrication technique.



**Figure 6 :** Part to part compacting pressure, maximum ejection pressure and green density of a F-0005 mix, compacted with and without die wall lubricant at room temperature.

For the second stability study, 600 rings (6.35 mm thick , 52 mm outer diameter and 43 mm inner diameter) were pressed at 645 MPa (46.8 tsi) using the die wall lubrication unit. It is worth mentioning that the mix used did not contain any internal lubricant. Compacting and maximum ejection pressures as well as part weight after reaching the steady state are presented in Figure 7, i.e. from the 250<sup>th</sup> to the 600<sup>th</sup> part. The corresponding average values and standard variations are given in Table 1.

These results show that low standard deviations were obtained for the weight and compacting pressure with values of 0.22% and 0.8% respectively. Furthermore, ejection pressure didn't reach the level usually recognized as a maximum limit in the literature (55 MPa or 4 tsi). Even if the ejection pressure for this particular material without internal lubricant was relatively high at 43.8 MPa, the standard deviation for this parameter remained relatively low (5.8%), and the pressure never exceeded the 55 MPa limit, confirming a good stability of the die wall lubrication unit. This result is noticeable, because one main objection to the use of die wall lubrication on industrial production comes from the risk that improper die wall lubrication occurs sporadically causing accelerated die wear and even tooling seizure.



**Figure 7:** Variation of the compaction and ejection properties of rings produced using die wall lubrication: a) parts weight, b) compacting pressure and c) maximum ejection pressure between the 250<sup>th</sup> and the 600<sup>th</sup> part.

**Table 1:** Characteristics of the 6.35 mm thick rings compacted using die wall lubrication technique.

Number of rings	350
Average Density, $g/cm^3$	7.11
Weight:	
Mean, $g$	31.19
Standard deviation, $g$	0.07
Standard deviation, %	0.22
Compacting pressure:	
Mean, $MPa$ ( $tsi$ )	645 (46.8)
Standard deviation, $MPa$	6.09
Standard deviation, %	0.8
Maximum ejection pressure:	
Mean, $MPa$ ( $tsi$ )	43.8 (3.17)
Standard deviation, $MPa$	2.54
Standard deviation, %	5.8

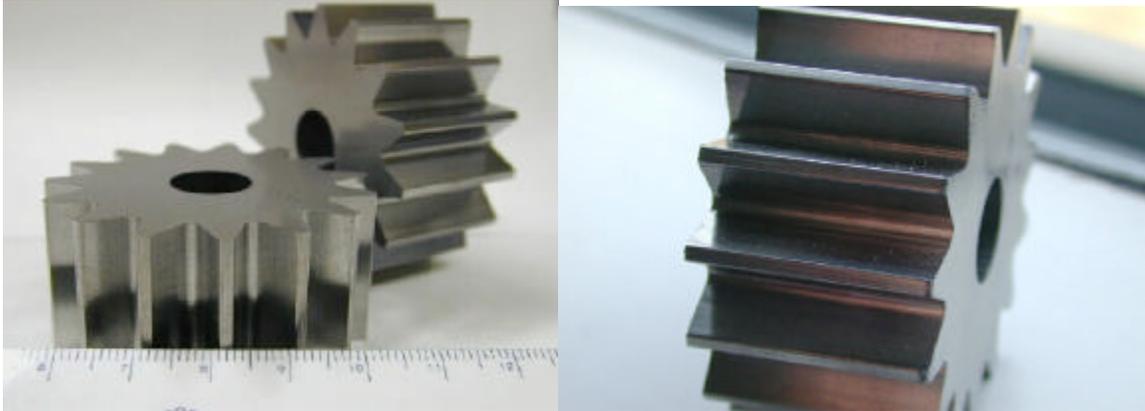
### **3. EVALUATION OF THE DIE WALL LUBRICATION SYSTEM WITH WARM PRESSING ON AN INDUSTRIAL PRODUCTION PRESS**

As previously mentioned in the introduction, P/M parts can be pressed to higher density by reducing the amount of internal lubricant and compacting at higher pressure and temperature, if a low level of friction on the die walls is maintained during the compaction and ejection process. The goal of this section is to evaluate the system under such demanding production conditions.

#### **3.a- Description of the part and the processing conditions used.**

The one level 15 teeth gear shown in Figure 8 was selected in order to maximize the friction surface in contact with the die walls. This part is pressed with the same die as the two level gears used in the previous section with a different lower punch. At a height of 1.78 cm, the friction surface was close to  $45.5\text{ cm}^2$ . It is noteworthy that this friction surface is eight times the friction surface of a standard 6.35 mm (1/4 in.) TRS bar. The compacting surface of the gear is close to  $13.5\text{ cm}^2$ .

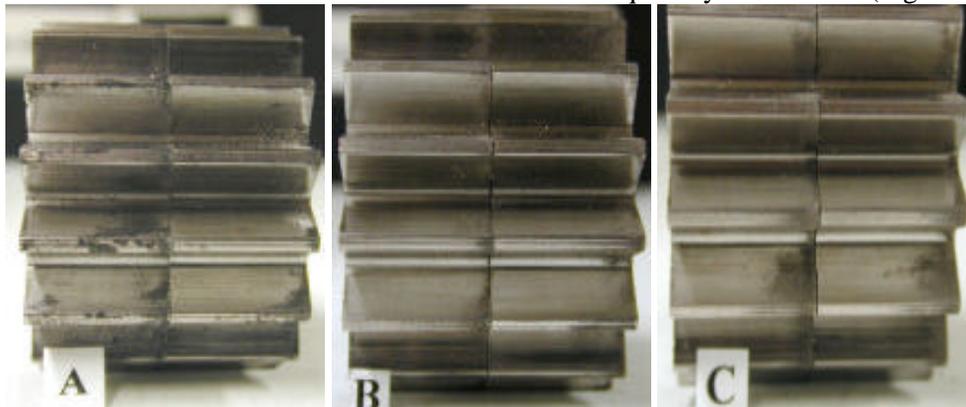
A FC-0208 mix was prepared in a “V” mixer by admixing 2 wt % of fine copper powder, 0.8 wt % of graphite and 0.25 wt % of warm pressing lubricant to a water atomized steel powder (ATOMET 1001) supplied by Quebec Metal Powders Ltd. The compaction and ejection characteristics at  $120^\circ\text{C}$  of this DWL mix were compared to the characteristics of a FC-0208 reference mix containing 0.75 wt % EBS compacted at room temperature and 620 MPa (45 tsi) without die wall lubrication. The weights, compacting forces and ejection curves were recorded for each part.



**Figure 8:** Typical view of the 15 teeth gear. Compacting surface =  $13.5 \text{ cm}^2$  ( $2.1 \text{ in}^2$ ).

### 3.b- Determination of the die wall lubrication parameters

Some preliminary tests were done by varying the amount of lubricant sprayed into the die cavity, while maintaining all other parameters constant. The qualities of the surface finish of green parts together with the ejection pressures were used to determine the optimum amount of lubricant to apply on the die walls. Figure 9 shows the surface finish of two juxtaposed gears warm compacted at 620 MPa using the die wall lubrication system and the specially selected die wall lubricant. In Figure 9A, the presence of darker areas can be associated with an excess of lubricant at the surface of the part. Lowering the quantity of lubricant (Figure 9C) led to an improvement of the surface finish, but the best surface finish was observed at the lowest quantity of lubricant (Figure 9B).



**Figure 9:** Surface finish of gears pressed at 620 MPa using die wall lubrication for three levels of external lubricant on the die walls. A: highest quantity, B: lowest quantity and C: intermediate quantity.

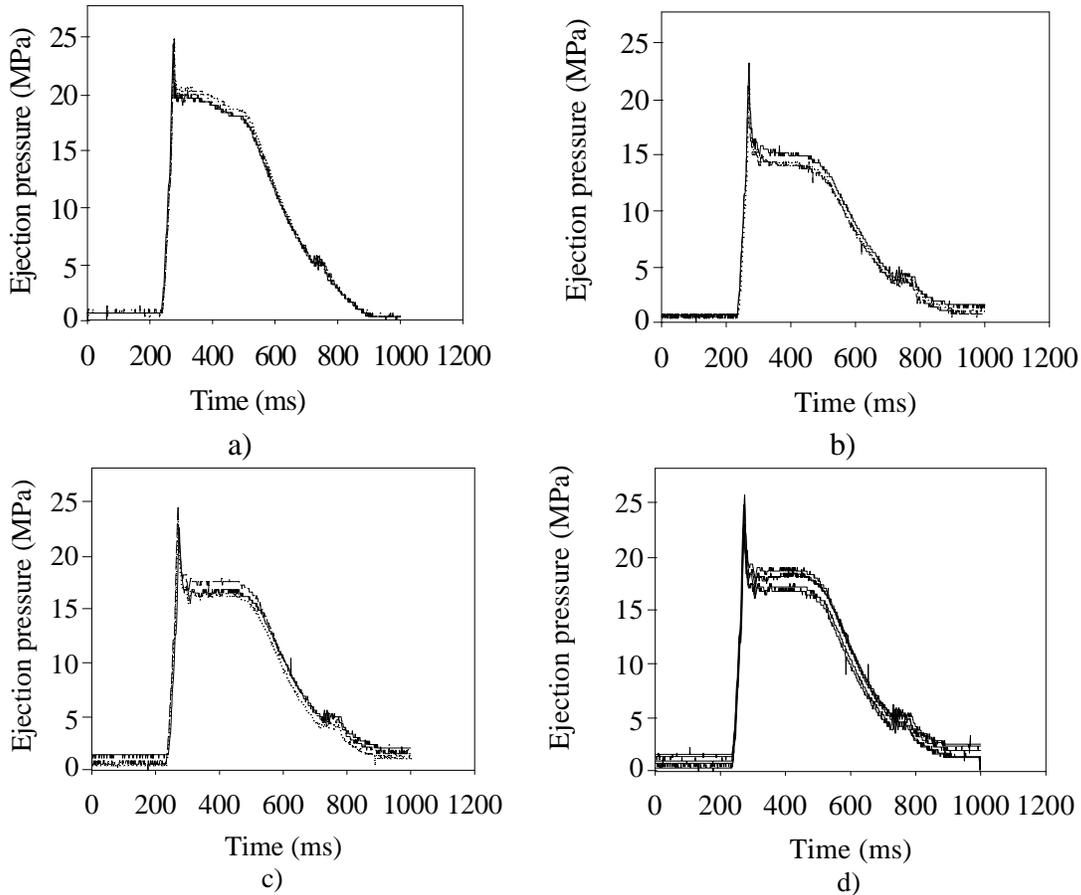
Since similar ejection forces were obtained regardless of the amount of lubricant sprayed on the die walls, it was decided to use the intermediate quantity of lubricant to prevent any damage of the die at high compacting pressure. Spray duration and fluidizing pressure were then optimized for this quantity of lubricant (case C) and respectively adjusted to 0.54 s and 20 psi.

### 3.c- Ejection pressures

A first series of 25 gears was compacted at room temperature and at 620 MPa (45 tsi) with the

reference mix containing 0.75% EBS wax. No external lubricant was applied on the die walls. Typical ejection curves obtained with this mix are presented in Figure 11a. The other mix was then warm pressed using the die wall lubrication unit with the optimized lubrication parameters. The die was maintained at 120°C and the powder mix was preheated to 72 °C. The compacting pressure was gradually increased in order to maintain ejection pressures below those observed with the reference mix. Figure 11b and 11c show typical ejection curves obtained for 2 sets of 25 gears compacted respectively at 620 and 827 MPa using the DWL mix. It is clear in Figure 11c that the sliding pressures corresponding to the horizontal segment of the ejection curves (17.2 MPa, 1.25 tsi) are lower for the DWL mix than for the reference mix (~19 MPa, 1.38 tsi). Furthermore, at 868 MPa (Figure 11d), the maximum ejection peaks or stripping pressures (25 MPa, 1.81 tsi) are similar to those obtained with the reference mix and the sliding pressures are still lower (17.9 MPa, 1.30 tsi against ~19 MPa, 1.38 tsi for the reference) indicating a better lubrication performance when using the DWL mix.

Therefore, the excellent performance of the die wall lubrication unit combined with adequate selection of the die wall lubricant easily enables warm compaction up to 827 MPa while maintaining ejection pressures under values observed for the reference mix compacted at room temperature and 620 MPa.



**Figure 11:** Ejection curves of the a) reference mix at 620 MPa (45 tsi), b) DWL mix, warm pressed at 620 MPa (45 tsi), c) DWL mix, warm pressed at 827 MPa (60 tsi), d) DWL mix, warm pressed at 868 MPa (63 tsi).

### 3.c- Green and sintered properties

The green densities of the 1.78 cm thick gears pressed at various compacting pressures and temperatures are given in Table 2 for the reference mix containing 0.75% wax and the DWL mix containing 0.25% warm pressing lubricant. These results clearly indicate that the use of die wall lubrication enhances reaching substantially higher densities than those achieved with the reference mix, with respectively 7.30 vs 7.06 g/cm<sup>3</sup>. Those high densities cannot only be attributed to both the higher intrinsic compressibility of the DWL mix at high pressure, due to the lower amount of internal lubricant, and to the increased ductility of steel powders at 120°C, but also to the good performance of the die wall lubricant during compaction and ejection, which minimizes the negative effect of friction with the die walls [15].

Table 2 also reports the percentage of densification, described as the pore free density (PFD), for the various conditions, as calculated with the equation given in references [8, 16]. For the standard FC-0208 mix without lubricant, the PFD is 7.74 g/cm<sup>3</sup>. When the amount of lubricant is increased to respectively 0.25 and 0.75 wt%, the PFD of the mix decreases to 7.61 and 7.37 g/cm<sup>3</sup>. These calculations show that the lubricant content is a major limitation for the densification of a mix, particularly when approaching the pore free density. In warm compaction, the maximum achievable green density is generally in the range of 98 to 98.5% of the PFD of the mix [15, 17, 18] because P/M parts expand after ejection. Therefore, for the mix containing 0.75% EBS wax, the maximum green density will be in the range of 7.22 to 7.26 g/cm<sup>3</sup> and 7.46 to 7.50 g/cm<sup>3</sup> for the DWL mix.

**Table 2:** Green densities of gears compacted at different pressures.

Mix	Compacting pressure (MPa) (tsi)	Compacting Temperature (°C)	Green density (std. dev.) (g/cm <sup>3</sup> )	Theoretical density (g/cm <sup>3</sup> )	%PFD
0.75wt%EBS	620 (45)	25	7.06 (0.01)	7.37	95.8
DWL mix	620 (45)	120	7.20 (0.01)	7.61	94.6
DWL mix	827 (60)	120	7.30 (0.02)	7.61	95.9

A limited quantity of green parts were characterized in order to evaluate their green strength. Results are reported in Table 3 along with sintered density evaluated after sintering in dissociated ammonia atmosphere for 30 minutes at 1160 °C. The crush strength of the green gears pressed with the DWL mix at 120°C is 20% higher than the value obtained with the reference mix. Besides, sintered density values are similar to those measured in the green state because of the presence of 2 wt % admixed copper, which causes an expansion of the gears during sintering.

**Table 3:** Crush strength in the green state and sintered density at different compacting pressures for the reference and die wall lubricated mixes.

Blend description	Compacting pressure (MPa) (tsi)	Crush strength (N/cm (lbf/inches))	Sintered density (g/cm <sup>3</sup> )
0.75 wt% EBS	620 (45)	1897 ± 81 (1084 ± 46)	7.09
DWL mix	620 (45)	2284 ± 212 (1305 ± 121)	7.20
DWL mix	827 (60)	2343 ± 142 (1339 ± 81)	7.30

## **4. CONCLUSION**

This paper presented an evaluation of a new approach to die wall lubrication under industrial conditions. The results obtained showed that the system used is stable and allows the compaction of thick specimens having large sliding surface at high density. The following were made:

- The die wall lubrication system including the dosing unit, the confining block and the die cover plate is stable, reliable and can be used on a production press to produce parts with good surface finish when suitable die wall lubricant and deposition parameters are selected.
- The die wall lubrication system can be used in combination with warm pressing.
- Green density of 7.30 g/cm<sup>3</sup> or 95.9% of the theoretical density were obtained with a 1.78 cm thick gear pressed in industrial conditions.
- Even for a compacting pressure of 868 MPa (63 tsi) and densities over 7.30 g/cm<sup>3</sup>, the ejection pressures remained lower than those observed with the reference mix containing 0.75% wax, pressed at 620 MPa (45 tsi) to a density of 7.06 g/cm<sup>3</sup>.
- The use of warm pressing with a die wall lubrication system is a good way to improve the green mechanical properties of P/M parts.

## **ACKNOWLEDGEMENTS**

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