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BENEFITS OF DIE WALL LUBRICATION FOR POWDER COMPACTION

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ABSTRACT

The achievement of high density at reasonable cost would be a definite advantage for the production of P/M components requiring high static and dynamic properties. The use of the electrostatic die wall lubrication technique with cold or warm powder compaction appears as a very attractive route to promote densification. It thus becomes very interesting to evaluate the benefit of this technique on the density gradient for parts with long die fill.

This paper presents a review of different case studies using die wall lubrication, and in particular, for some parts with long die fill compacted with a laboratory press or with an industrial mechanical press. Special attention is paid to the level and distribution of green density as a function of the lubrication performance.

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ABSTRACT

The achievement of high density at reasonable cost would be a definite advantage for the production of P/M components requiring high static and dynamic properties. The use of the electrostatic die wall lubrication technique appears as a very attractive route to promote densification. By reducing the level of friction at die walls, this technique should have the potential to also reduce density variations in powder compacts, particularly for parts having a large sliding surface or a long die fill.

This paper presents two case studies of parts having high aspect ratio compacted using die wall lubrication either on a laboratory press or on an industrial mechanical press. Special attention is paid to the axial density distribution of the green compacts as a function of the compacting pressure and the type of lubrication (admixed or die wall lubrication).

INTRODUCTION

Since the beginning of the nineties, many authors have demonstrated the advantages of using die wall lubrication (DWL) associated with a decrease of the admixed lubricant content to improve density and mechanical properties of P/M parts [1, 2, 3, 4]. By maintaining good lubrication at die walls during the compaction and the ejection of parts, this technique was shown to be very efficient, in particular when combined with warm pressing to increase the density of parts. However, until now, literature focused mainly on the use of very high compacting pressure to reach the highest possible density for relatively simple parts with a low aspect ratio. With the development of die wall lubrication systems that enable the application of external lubricants on die walls in industrial conditions even for long die fill parts [5, 6], it becomes interesting to investigate the benefits of DWL specifically for parts having a large sliding surface or a long die fill.

A point to consider regarding the compaction of complex parts is the amount of admixed lubricant required to press the parts. Recent studies have shown that, using DWL, the content of admixed lubricant required to optimize the densification and achieve a good particle rearrangement during pressing was very low, well under 0.2 wt% [7, 8, 9]. However, this was done on simple parts like tensile or transverse rupture specimens. Studies conducted at the Industrial Materials Institute (IMI) in collaboration with QMP, have shown that as the aspect ratio of a part is increased, the optimum level of admixed lubricant is not only dictated by the ultimate reachable density (% Pore Free Density), but also by the level of friction at die walls. Indeed, if the reduction of the admixed lubricant is required to avoid the inhibition of compaction at high pressure due to the volume occupied by the lubricant, the admixed lubricant still play an important role on wall lubrication when combined with a die wall lubrication system. More precisely, a high die fill part easily processed with a mix containing 0.2 wt% of admixed lubricant and with DWL became practically impossible to process with the same mix containing only 0.1 wt% lubricant due to higher ejection forces and bad surface finish (galling). Therefore, an optimum content of admixed lubricant must be determined as a function of the complexity of parts and the lubrication performance at the die walls.

In addition to the possibility of applying higher compacting pressures while maintaining adequate ejection pressures, another significant advantage of DWL for parts having a long die fill might be the reduction of the pressure loss along the part height due to less friction on die walls. This reduction should bring a decrease of the axial density variation and an increase of the average green density of the part. Besides, it is worth mentioning that density variations in a powder compact may not only be generated by friction at the die walls, but also by the apparent density variations of the powder mix in the die due to poor die filling, magnetized die, mix segregation, or by a poor particles rearrangement or non optimal tool movements during compaction.

The objective of this study was to quantify the effect of DWL on the reduction of axial density gradient in a high aspect ratio part and, consequently, on the increase of the average part density.

EXPERIMENTAL PROCEDURE

Laboratory Scale Evaluation

All experiments of powder compaction at the laboratory scale were carried out by using a highly compressible water-atomized iron powder (ATOMET 1001, supplied by Quebec Metal Powders Limited) with different quantities of admixed zinc stearate (ZnSt) lubricant. Weight fraction of lubricant content ranged from 0 to 2 wt%.

The behavior of the powder during compaction was evaluated using the Powder Testing Centre (model PTC-03DT). This apparatus consists of an instrumented cylindrical die operating in a single action mode. This lab press allows continuous recording all along the compaction and ejection process, of the punch displacement, the applied pressure and the pressure transmitted to the stationary punch. To evaluate the effect of the lubrication mode, a device was designed to apply a thin layer of lubricant on the die wall. The principle used by this apparatus is based on tribostatic electrical charge produced on lubricant particles when they are carried by a flow of air through a small Teflon tube.

Cylinders having a height of ~ 8 mm (aspect ratio of 3.36 compared to 1.4 for a standard ¼" TRS bar) were compacted at 25°C and 45 tsi in a D2- high speed steel die having a diameter of 9.525 mm at a compacting rate of 1 mm/sec. Powder mixtures containing from 0.5 to 2 wt% ZnSt were compacted without die wall lubrication (DWL), while powder mixtures containing from 0 to 0.75 wt% ZnSt were compacted with ZnSt external lubricant applied on the die walls. At least 5 specimens were pressed for each material and condition.

For the different admixed lubricant contents and DWL conditions, friction at the die walls was evaluated from the pressure drop between the pressure applied on the moving lower punch and the pressure transmitted to the stationary upper punch (Figure 1).

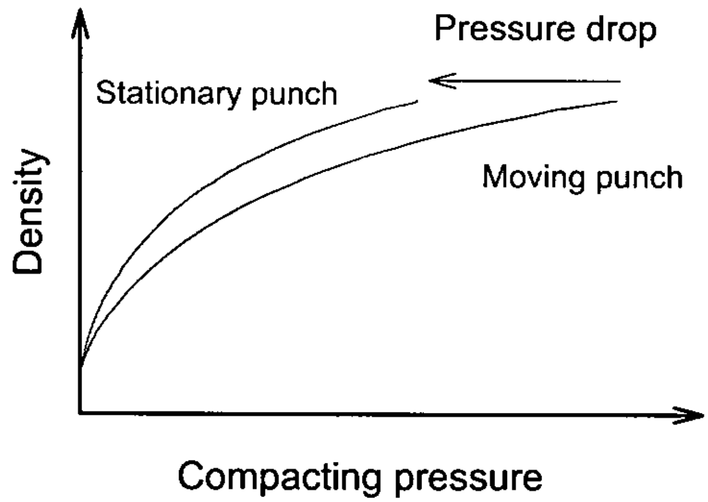

Figure 1 : Evaluation of friction at die walls on the single action laboratory press

With this system, it is important to realize that since it is a single action press, the cylinder with an aspect ratio of 3.36 has a friction behavior similar to a cylinder with twice its thickness or an aspect ratio of 6.72 on a double action press or with a floating compaction die.

Production Scale Evaluation

The evaluation on production scale was done with a fully instrumented 150 ton mechanical industrial press, equipped with a patented electrostatic die wall lubrication system for deep cavities (long die fill) developed at IMI [2,5]. The press was monitored with lower punch strain gages giving the complete ejection curves for all parts produced.

The part used in this study is a one level 15 tooth straight spur gear shown in Figure 2. The external diameter of the gear is 5 cm, its thickness was set to 2.54 cm for all experiments giving a sliding surface of ~65 cm^2 and an aspect ratio of 4.70.

Two different powder mixes were evaluated. The first one, the reference mix (REF), is a FC-0208 mix containing 0.8 wt% graphite, 2.0 wt% copper and 0.75 wt% Acrawax C atomized. The second one, referred as DWL mix, is the same mix but containing only 0.2 wt% Acrawax C atomized. The experiments with this mix were carried out with the DWL system and zinc stearate as external lubricant. These two powder mixes were compacted under different compacting pressures.

After compaction, green density was measured by water displacement. Axial density variations were also determined on at least 3 gears per condition by cutting 5 mm thick slices (top, middle, bottom) from the gears in the green state. This method has the advantage to be simple and rapid, but because it gives an average density of each slice, it may underestimate the density gradient.

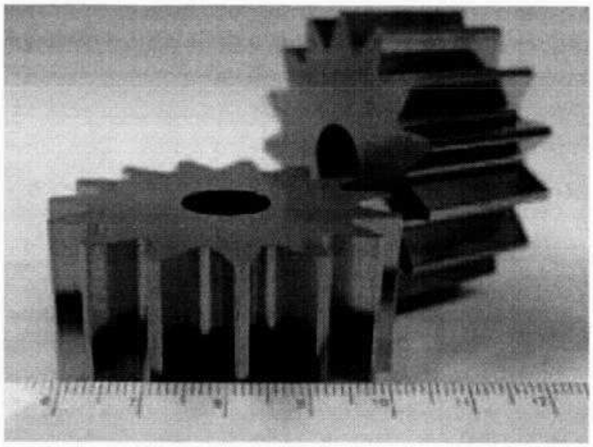

Figure 2: Gears used on the production press to study the axial density variations.

RESULTS AND DISCUSSION

Laboratory Scale Evaluation

Figure 3 illustrates the effect of admixed lubricant on the pressure transmitted from the moving to the stationary punch of the PTC apparatus. It is seen that the ratio between the transmitted and the applied pressure increases as the amount of admixed lubricant increases. This figure also shows that higher ratio of transmitted/applied pressure are obtained in presence of die wall lubrication. In fact, approximately 1 and 2 wt% admixed lubricant is required to reach the same ratio as, respectively, with 0% and 0.5 wt% admixed lubricant plus die wall lubrication. It takes approximately 1.6 wt% admixed lubricant to reach the same ratio of transmitted/applied pressure as with only 0.2 wt% admixed lubricant combined with die wall lubrication.

As shown in Figure 3, the transmitted pressures are significantly different for different lubrication modes and admixed lubricant levels. This difference helps to realize how important is the effect of friction at die walls and how much it could generate density variations on a long die fill part. In fact, in this particular case, it should be possible to get, with only 0.2 wt% admixed lubricant combined with die wall lubrication, a lower axial density variation than with the use of a regular P/M mix containing up to more than 1 wt% admixed lubricant at a compacting pressure of 45 tsi. It is also interesting to note that friction at the die wall tends to decrease with the increase of the admixed lubricant content up to approximately 0.5 wt% when using DWL. On the other hand, in the absence of DWL, the friction i.e. pressure loss is not yet stabilized even at 2 wt% admixed lubricant.

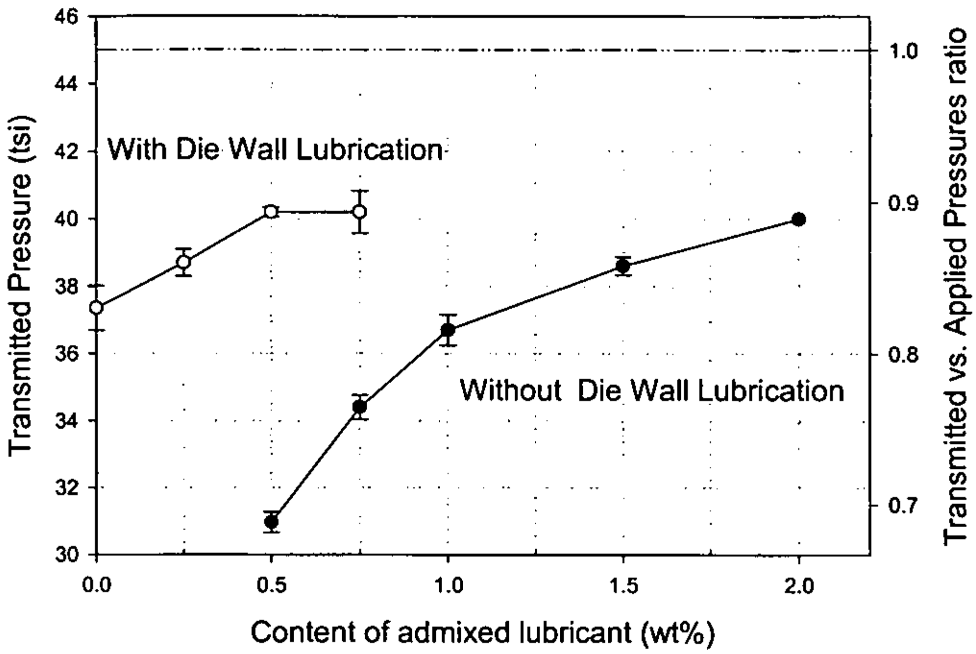

Figure 3: Effect of lubrication mode and admixed lubricant content on the transmitted pressure ratio, for cylinders (aspect ratio of 3.36) pressed with a single action press at a compacting pressure of 45 tsi.

Production Scale Evaluation

Figure 4 shows the compressibility curves of the two different mixes compacted with and without DWL on the production press. For the specific conditions used in this study (type of gear and die, type of powder mix), the use of the die wall technology with a low admixed lubricant content mix lead to an improved densification for all the compacting pressure range, and even more for pressures higher than 50 tsi. The density of the reference mix reaches a plateau at about 7.2 g/cm^3 (~ 97.6 %PFD) at a compacting pressure of about 63 tsi. At the same compacting pressure, the density of mix compacted with die wall lubrication is still increasing and reaches a level above 7.35 g/cm^3 (~96.4 %PFD). It is worth mentioning that the pressure at which the benefit of DWL becomes significant will depend on the complexity of the parts and the lubrication performance of the DWL mix. Indeed, previous work at IMI revealed that important improvement in densification could occur at a compacting pressure as low as 40 tsi, for higher aspect ratio parts.

The dashed lines of Figure 4 illustrate the effect of a variation of transmitted pressure due to friction at the die walls on the axial density gradient of green parts pressed from different mixes and at different pressures. At a low pressure (~35 tsi), density variations caused by the ΔP should be slightly higher for the DWL mix ($\Delta\rho_3$ and $\Delta\rho_1$) since its slopes is higher, and this tendency increases all along the compacting pressure curves. At 63 tsi, the density of the reference mix is saturated and its slope is nil ($\Delta\rho_4$ versus $\Delta\rho_2$ for the DWL mix). Therefore, the axial density variation in the parts made from the reference mix at those levels of pressure should be very low. However, this result should not be explained by the good lubrication and the low levels of friction at the die walls, but rather by the fact that a large portion of the gear's height is in the over pressing range to allow sufficient pressure to be transmitted to the center of the gear for complete densification. The decrease of the density gradient in a part by using this technique can sometimes results in less resistant parts due to particles de-cohesion (micro cracks,) in the upper and lower portion of the part during the pressure relief. Highly pressurized entrapped air in the porosities can, due to axial spring back, break the inter particle connections formed by cold welding during consolidation.

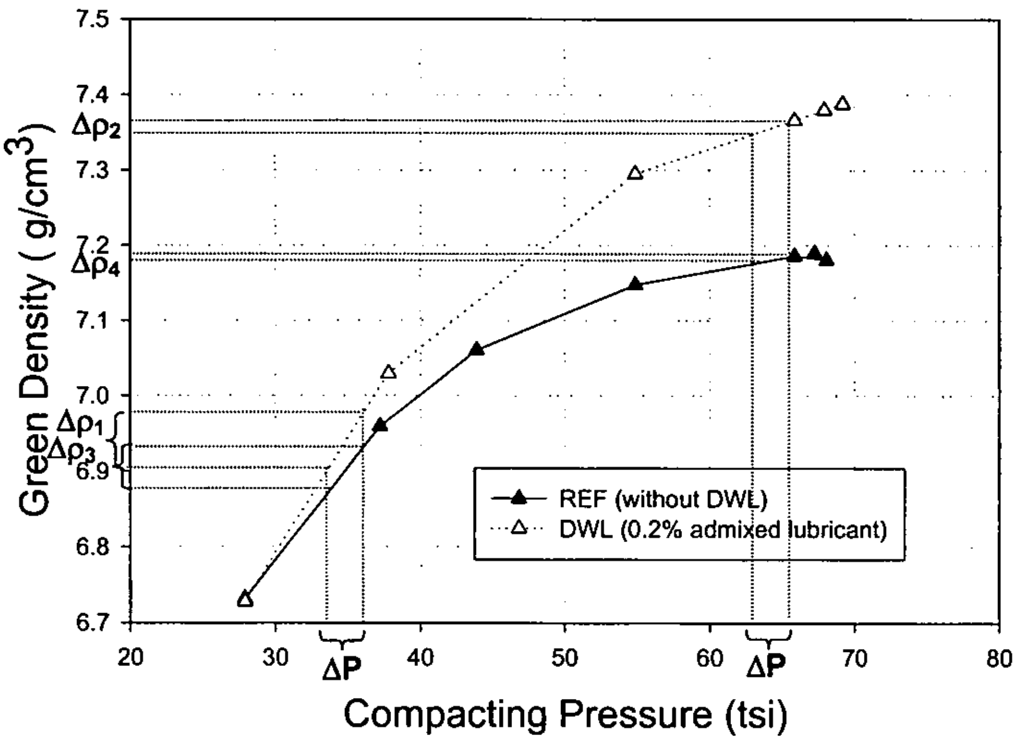

Figure 4: Compressibility curves of the reference mix (0.75 wt% EBS) and the die wall lubricated mix (0.2wt% EBS) for the 25.4 mm thick gear.

Figures 5 and 6 together with Table 1 compare the measured axial density variation with what could have been forecasted from the ΔP of the figure 4 at different compacting pressures.

At low compacting pressures (28 tsi), similar green density and axial density variations in the parts were obtained for both the reference and the DWL mixes. As the compacting pressure further increases, the axial density gradients in the parts compacted with DWL decrease to reach a very low level of gradient (<0.03 g/cm^3) at compacting pressures of 55 tsi and higher. On the other hand, the axial density gradient in the parts compacted from the reference mix without DWL remains quite constant (0.08 g/cm^3) up to 55 tsi. For 67 tsi, however, a very low axial density gradient was also observed. As explained earlier, at this high compacting pressure, over pressing with the reference mix should have helped to reduce the density gradients at the same low level observed when using DWL.

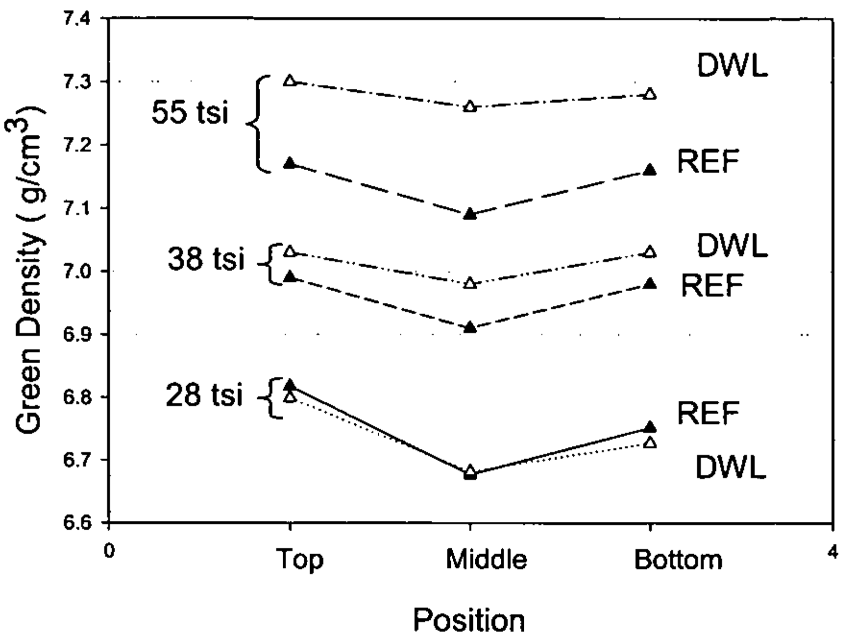

Figure 5: Axial density variation in the parts produced with the reference and the DWL mixes, as a function of the compacting pressure.

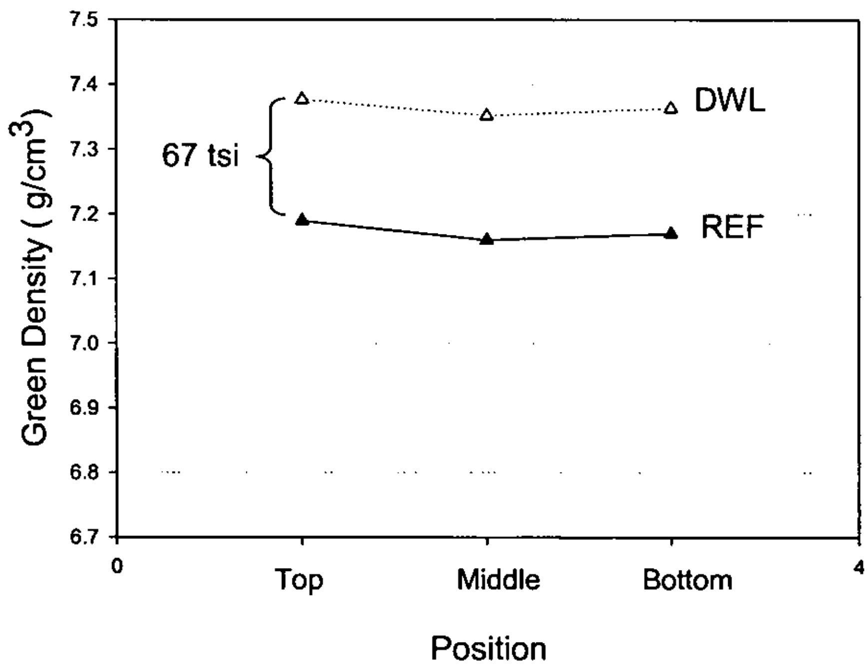

Figure 6: Axial density variation in parts compacted at 67 tsi with the reference and the DWL mixes.

Given that the slope of the compressibility curve for the DWL mix is still high at 55 tsi (Figure 4), one will expect a large gradient in the parts. However, the low density gradient observed is explained by a very low level of friction at the die wall interface. Indeed, when using die wall lubrication, the ratio of transmitted/applied pressure is far better, as seen during the laboratory tests, giving a smaller pressure drop along the part height. This decrease of pressure loss due to lower friction along the part height with the use of DWL is sufficient to override the effect of the higher slope all along the compressibility curve.

Table 1: Ejection stripping pressure, average green density and axial density gradient in the parts pressed at different compacting pressures with and without the DWL technique.

FC0208 Powder mixtures	Compacting Pressure tsi	Ejection Stripping Pressure tsi	Green density g/cm^3	Axial density variation g/cm^3
REF mix	28	1.51	6.73	> 0.08
DWL mix	28	1.23	6.73	> 0.08
REF mix	38	1.71	6.96	0.08
DWL mix	38	1.5	7.03	0.05
REF mix	55	1.84	7.15	0.08
DWL mix	55	1.77	7.30	0.03
REF mix	67	1.83	7.19	0.02
DWL mix	67	1.72	7.38	0.02

*REF mix : 0.75 wt% admixed EBS; **DWL mix : 0.2 wt% admixed EBS

Therefore, two main reasons may explain why DWL results in higher average densities in parts. The first and well-known reason is the increase of the theoretical density of the mix resulting from the use of a lower admixed lubricant content. However, to benefit of this effect, parts must be pressed at a tonnage where compaction of the regular mixes begins to be inhibited by the volume occupied by the lubricant or the organic materials in the mix. Ejection and surface finishes become major issues at those tonnages. The second main reason for the average density increase with the use of DWL is, as seen previously, the decrease of friction at die walls, which in turn decreases the axial density gradients in the parts.

Finally, it is interesting to investigate what occurs with the ejection curves of high die fill parts with or without DWL, particularly at high compacting pressures, where the two previously discussed phenomena contribute to increase density. In fact, as parts become thicker, sliding distances to eject the parts become more important and lubrications problems such as galling, scoring or stick and slip become more likely to happen. Figure 7 reports complete ejection curves at 38 and 67 tsi. Despite the significant higher density obtained with the DWL mix containing only 0.2 wt% admixed lubricant as compared to the reference mix (7.38 vs. 7.19 g/cm^3 at 67 tsi), slightly lower ejection pressures are obtained when using DWL. This clearly shows the benefit of this technique even for parts having a high aspect ratio. It is worth mentioning that the reference mix in this study performed relatively well with a relatively low level of friction even at high tonnages. Previous work with other powder formulations showed that the friction is often too high at high compacting pressures, impeding the compaction of these materials at such high tonnages without die wall lubrication [2].

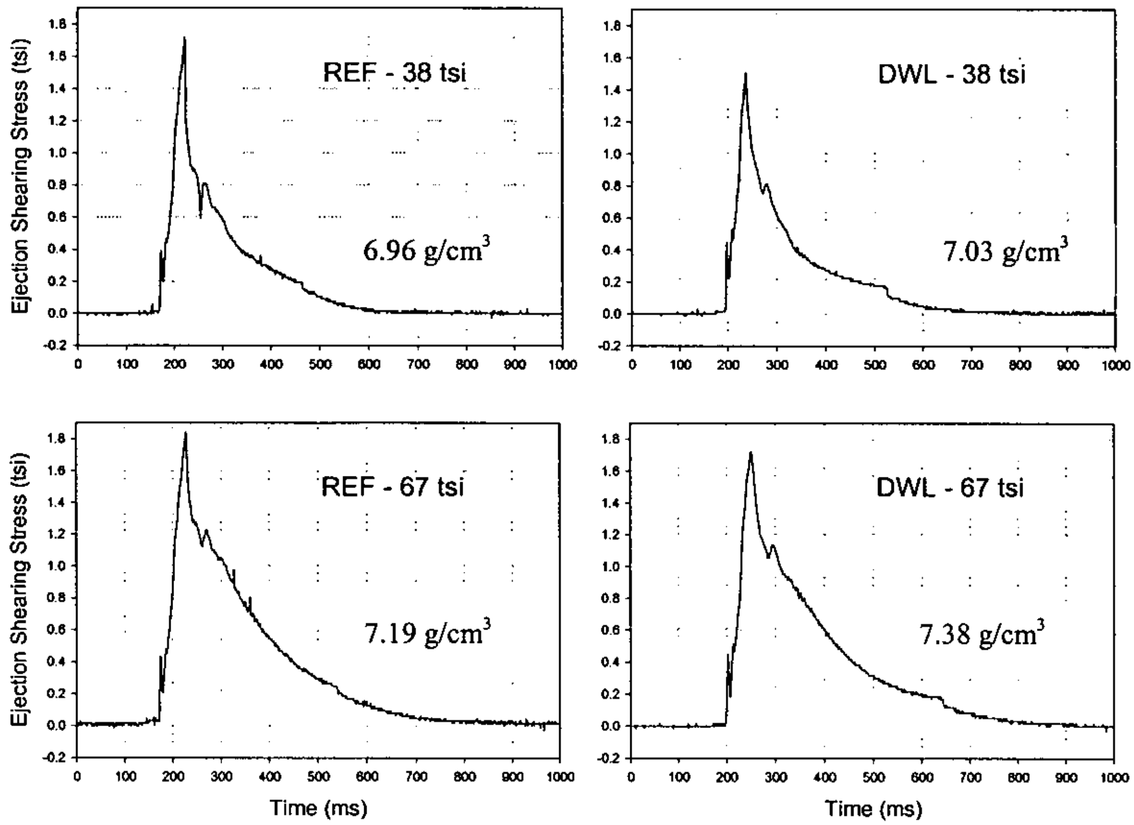

Figure 7: Ejection curves of gears compacted on the production press at 38 tsi and 67 tsi.

CONCLUSIONS

In addition to the recognized benefits of die wall lubrication, namely less lubricant burn off giving cleaner furnaces with improved refractory life, shorter delubbing time resulting in higher throughputs, improved green and sintered mechanical properties due to pressing at higher densities, the present study on compaction of parts with or without the help of die wall lubrication for high die fill parts allows to draw the following conclusions:

- The internal lubricant plays an important role on die wall lubrication even at 0.2 wt% admixed lubricant. The amount of admixed lubricant must be optimized as a function of the part complexity and the lubrication performance of the mix.
- The use of die wall lubrication allows an important decrease of friction at die walls and of the axial density variations in thick parts. In this study the axial density gradient was reduced by a factor of three, at 55 tsi, by using die wall lubrication. This decrease in axial density gradient and in friction at die walls could lead to higher average density, less green cracking at ejection due to less tooling deflection and less tool wear.

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REFERENCES:

1 W.G. Ball, P.F. Hibner, F.W. Hinger, J.E. Peterson, R.R. Phillips, "Replacing Internal with External Lubricants: Phase III. Tribostatic Application of Lubricants onto Die Walls", *Adv. Powder Metall. & Particul. Mater.*, Vol. 2, Part 6, 1996, pp. 3-15.

2 P. Lemieux, S. Pelletier, P.-E. Mongeon, Y. Thomas, L.P. Lefebvre, F. Chagnon, "A New Approach to Die Wall Lubrication for P/M Applications", *Adv. Powder Metall. & Particul. Mater.*, 2001, pp.3.1-3.13.

3 P. Lemieux, Y. Thomas, P.-E. Mongeon, S. Pelletier, S. St-Laurent, "Combining Electrostatic Die Wall Lubrication and Warm Compaction to Enhance Green Properties of P/M Components", *Adv. Powder Metall. & Particul. Mater.*, 2002, pp.3.34-3.46.

4 M. Kondoh, H. Okajima, "High Density Powder Compaction Using Die Wall Lubrication", *Adv. Powder Metall. & Particul. Mater.*, 2002, pp.3.47-3.54.

5 P.-E. Mongeon, S. Pelletier, A. Ziani, U.S. Patent #6,299,690, "Die wall lubrication method and apparatus"

6 T. Cadle, J. Mandel, P. Roskopf, U.S. Patent # *6,190,605*, "Dry Die Wall Lubrication".

7 T. Tsuchida, H. Yaguchi, T. Sawayama, M. Sato, Y. Sseki, N. Akagi, U.S. Patent #6,344,169, "Method for Compaction of Powders for Powder Metallurgy".

8 Y.Y. Li, T.L. Ngai, D.T. Zhang, Y. Long, W. Xia, « Effect of Die Wall Lubrication on Warm Compaction Powder Metallurgy", *J. Mater. Process. Technol.*, Vol. 129, 2002, pp. 354-358.

9 T.L. Ngai, W-P Chen, Z-Y. Xiao, L-P. Wen, Y-B. Wu, « Die Wall Lubricated Warm Compaction of Iron-Based Powder Metallurgy Material », *Transaction of the Nonferrous metals society of China*, Vol. 12, No. 6, 2002, pp. 1095-1098.