Characterization of Different Lubrication Approaches to Improve Green Machinability

Lapointe, Philippe; Blais, Carl; Pelletier, Sylvain; Thomas, Yannig; St-Laurent, Sylvain

Publisher’s version / Version de l'éditeur:

Proceedings of EuroPM2007, 2007-10-15

Characterization of Different Lubrication Approaches to Improve Green Machinability

Philippe Lapointe*, Carl Blais*, Sylvain Pelletier⁺, Yannig Thomas⁺, Sylvain St-Laurent⌘

* Department of Mining, Metallurgical and Materials Engineering, Université Laval, Quebec City, Quebec, Canada.

⁺ Powder Forming Research Group, Industrial Materials Institute – National Research Council, Boucherville, Quebec, Canada.

⌘ Quebec Metal Powders Ltd., Sorel-Tracy, Quebec, Canada.

Philippe Lapointe
Dept. of Mining, Metallurgical and Materials Engineering
Université Laval
Pavillon Adrien-Pouliot
Local 1728
Québec, QC, CANADA
G1K 7P4

Abstract

Development of high performance components using powder metallurgy requires excellent geometrical conformance as well as hard microstructures. Thus, machining operations are used regularly to meet the required tolerances. This situation raises two problems. Firstly, the machining behaviour of PM components is widely recognized to be difficult due to the presence of porosity. Secondly, hard microstructures such as tempered martensite and bainite amplify the machining problems of PM materials. The development of new lubricant/binder systems has opened new possibilities in this regard. Indeed, some new binder/lubricant systems allow a significant increase of green strength of PM components making green machining possible. Therefore, it is possible to machine PM components before sinter-hardening thus minimizing cutting forces and tool wear. Moreover, the microstructure of green components is not yet transformed into harder constituents. This paper presents results obtained by comparing several methods of using binder/lubricants to optimize green machining.

Introduction

Powder metallurgy is well-known to produce near-net-shape components. However, in many cases, machining operations are necessary to achieve the desired complex geometry and final size. Unfortunately, the machining of PM parts could be a challenging operation. Indeed, the residual porosity inherent to the P/M forming processes reduces thermal conductivity [1,2,3] and induces micro vibrations which are very harmful to the life of the cutting tool [1,2,3]. The lower thermal conductivity has the inconvenient of significantly raising the temperature at the cutting tool/chip interface. This phenomenon along with the increased level of micro vibrations make the machining of P/M components considerably more difficult. Moreover, previous studies [4] have shown that the processes involved in the fabrication of metal powders were responsible for the formation a higher amount of hard particles such as oxides compared to other shaping methods. The presence of these hard particles is also accountable for the difficulties related to the machining of P/M components.

In order to alleviate the problems afore mentioned, various methods have been developed over the years. For instance, the addition of MnS is well-known to improve machining by acting as lubricant at the tool/chip interface and by promoting the formation of smaller chips [5-10] without having a major impact on the mechanical properties. Other additives such as lead, tin, BN, tellurium and many others can be used to achieve the same goals as the MnS [2,3,4,8]. Another way to lighten the impairing effects caused by the presence of residual porosity is to impregnate the components with various materials such as oil, resin or to infiltrate with copper. Doing so, lubrication as well as thermal conductivity are increased and the micro vibrations are significantly lowered. However, this technique can turn out to be quite expensive, especially when using copper infiltration. One very promising technique to reduce the drawback of machining is green machining, or the machining of components in their green state. The latest developments in binder/lubricant and blending technologies allowed to significantly increase the green strength, making green components able to withstand the forces involved during machining. Previous studies showed that the green machining of components produced with dedicated lubricant/binder could allow one to increase machining speed while significantly decreasing tool wear without substantially degrading mechanical properties [11].

Several systems combined with compaction methods may be used to increase green strength. Typical binder/lubricant systems such as FLOMET HGS (reference QMP) were specifically developed for green machining several years ago. The green strength of that system is maximized when a curing treatment of green parts is performed prior to the machining operation. This treatment allows the polymer to soften and to create a polymeric network throughout the component. Furthermore, it ensures a better distribution of the binder/lubricant all over the component, which results in better lubricating properties during machining. Unfortunately, this operation requires an extra step in the fabrication process leading to a decrease in productivity. New low melting point lubricants were also recently developed to achieve higher density. Due to their nature, these lubricants allow achieving higher green strength and better lubricant distribution after compaction compared to conventional lubricants. Finally, warm compaction of dedicated lubricant/binder systems is another method to increase green strength, This alternative method, due to the higher compacting temperature used, allow the binder/lubricant to create a polymeric network better distributed during the compaction process. The green strength achieved by warm compaction is similar to that achieved with FLOMET HGS with curing treatment.

The green machining behaviour of different binder/lubricant systems pressed by cold or warm compaction are presented in this paper. In particular, the green strength, the cutting forces and the average breakouts width of machined components are presented and discussed.

Experimental procedure

Material investigated

The machinability of four mixes was investigated during this study. Each mix was based on the ATOMET 4001 from Quebec Metal Powders Ltd. (Fe with 0.15%-wt Mn and 0.5%-wt Mo) to which 4%-wt Ni, 1.5%-wt Cu and 0.6%-wt graphite were admixed. Table 1 presents the amount and the type of binder/lubricant along with the compaction temperature used for each mix.

Mix	Binder/lubricant		Compaction Temperature	
	Content (%-wt)	Type	Die (°C / °F)	Powder (°C / °F)
REF	0.75	EBS wax	60 / 140	Amb.
HD	0.58	HD lubricant	60 / 140	Amb.
WP	0.55	WP binder/lubricant	120 / 248	90 / 194
HGS	0.65	HGS binder/lubricant	60 / 140	Amb.

Table 1 - Percentage and type of binder/lubricant and compaction temperature used for each mix studied

The REF mix containing a conventional ethylenebisstearamide wax (EBS) was used as the reference for this study. The compaction temperature was also the same as those typically encountered during normal compaction in the industry. The name HD stands for High Density. As such, the concentration of lubricant is slightly lower than the one used for the REF mix. The type of proprietary lubricant added in this mix has no binding properties and accordingly no further heat treatment is required to improve green strength. The designation WP refers to warm compaction. As seen in table 1, the compaction temperatures for the die and the powder are higher for the WP mix than for the other mixes. As explained in the introduction, compacting this type of powder at these temperatures allows the binder/lubricant to be partially melted and to form a polymeric network that reinforces the component while at their green state. This phenomenon is possible due to the polymeric nature of the binder/lubricant and his binding properties. On the other hand, the HGS mix is pressed at normal temperatures. Since it also has binding properties, a curing treatment is necessary to maximize green strength. In this case, the treatment consists in leaving the components for one hour at 190°C (374°F) in air. For this reason, half the components using the HGS binder/lubricant were submitted to the curing treatment in order to evaluate its impact on machinability.

Green Machining

Gears were compacted for each mix using a Gasbarre 150-ton mechanical press at pressures of 689 MPa (50 TSI), 758 MPa (55 TSI) and 827 MPa (60 TSI). The gears had fifteen teeth, 5.08 cm (2 in) of outside diameter, 1.27 cm (0.5 in) of inside diameter and 1.27 cm (0.5 in) in height as illustrated on figure 1. The green densities of the mixes were measured using the MPIF standard 42 [12]. The results obtained from these tests are presented in table 2. It is seen that the density does not vary much with the compaction pressure, typically 0.06 g/cm^3 from 689 MPa to 827 MPa. This can be explained by the fact that a these relatively high pressures the compressibility curve adopts an asymptotic behaviour, hence the low variation in density. Besides, there are small differences in density from one mix to another. The density of the REF mix seems to be slightly lower than the density of the other mixes (about 0.06 g/cm^3 lower). Even though this difference is not considerable, special care will be required when interpreting the results. After compaction, a 6 mm (0.234 in) groove was machined on the gears using a Mazak Quick Turn Nexus 100 lathe. The cutting tool used was a GIP6.00E-0.80 IC-9015 manufactured by Iscar. Every groove was machined using a surface speed of 457 m/min (1500 ft/min) and a feed rate of 0.0254 mm/rotation (0.001 in/rotation). These conditions were determined as being optimum in a previous study [13].

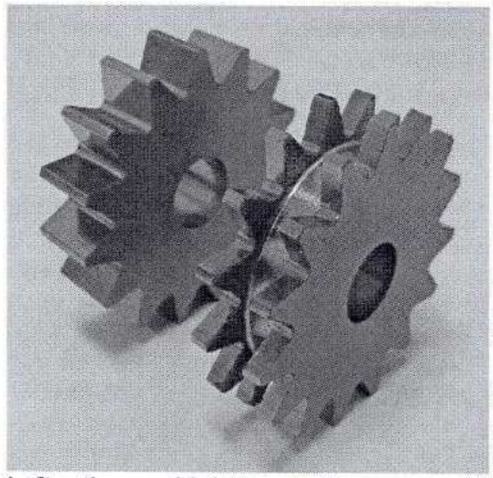

Figure 1 – Gears before and after the machining operation

Mix	Green Density (g/cm^3) @ 689 MPa / 758 MPa / 827 MPa
REF	7.15 / 7.20 / 7.19
HD	7.24 / 7.26 / 7.28
WP	7.20 / 7.24 / 7.27
HGS	7.18 / 7.23 / 7.26

Table 2 – Green densities of each mix for the specified compaction pressure

Characterization of Machining Performance

As mentioned in the introduction, green strength, cutting forces and surface finish were characterized in this study. Indeed, previous studies showed that the cutting forces and the measurement of breakout widths were an effective way to evaluate the green machining performance of different binder/lubricant systems studied [13].The green strength was measured according to the procedure explained in the MPIF standard 15 [12]. The cutting forces were measured using a Kistler dynamometer (model 9443B). The surface finished was quantified by measuring the average breakout width. The breakout width is the length on which particles were pulled out when the cutting tool leaves the teeth during machining. This measurement was performed by carrying out an image analysis routine. First, micrographs of the machined teeth were acquired and then fifty measurements per tooth were measured in order to get the average breakout width. Figure 2 illustrates the approach used during the image analysis routine developed by Robert-Perron et al. [13].

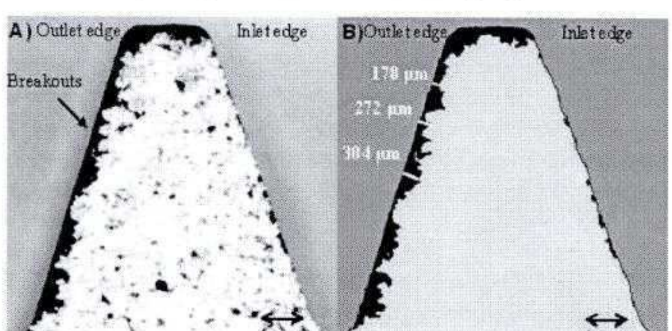

Figure 2 – Typical micrographs used for the image analysis routine

Results and Discussion

Table 3 summarizes the results obtained. It shows that the results do not change significantly as a function of the various compaction pressures. Once again, this is explained by the asymptotic behaviour of the powders once they are compacted at these relatively high pressures in axial pressing.

One interesting result stemming from table 3 is that cutting forces do not increase as green strength goes up. Actually, the results seem to show the opposite. There is a R^2 factor of 0.73 related to this series of results. Nevertheless, a previous study [13] clearly showed that green strength did not have a significant influence on cutting forces. According to this study, lubricating properties of the binder/lubricant have the greatest influence on the cutting forces. During machining, a binder/lubricant with good lubricating properties would form a thin film at tool/chip interface and lower the cutting forces. For instance, the REF mix has the lowest green strength and yet the highest cutting forces. The low green strength is explained by the nature of the EBS lubricant that smears during mixing at the surface of the powder particles and forms a thin layer with low mechanical strength, which limits microwelding during compaction. The larger cutting forces are also explained by the nature of the lubricant. Indeed, lubricants which are in fact a wax usually present inferior lubricating properties than polymeric binder/lubricants like the ones used for the WP and HGS mixes.

Mix	Green Strength MPa	Cutting Forces N	Breakouts width µm
REF	14 / 14 / 14	158 / 156 / 157	840 / 817 / 861
HD	27 / 26 / 27	142 / 144 / 144	451 / 434 / 419
WP	28 / 28 / 29	130 / 131 / 133	285 / 298 / 290
HGS	22 / 22 / 24	125 / 128 / 129	416 / 443 / 434
HGS Cured	39 / 38 / 38	116 / 116 / 115	215 / 246 / 261

Table 3 – Green strength, cutting forces and average breakouts width measured for each mix at compaction pressures of 689 MPa / 758 MPa / 827 MPa

Another aspect to take into consideration is the concentration of lubricant used. For instance, both lubricants used for the REF mix and the HD mix do not have binding properties. In that case, all other things being equal, lowering the concentration of lubricant helps increasing green strength because it promotes the formation of mechanical bonds. On the other hand, since binder/lubricants help strengthening the components, a higher concentration of the latter generally increases green strength. That is one of the reasons why the WP mix has a slightly lower green strength than the HGS mix after curing. Of course, the compaction temperature and the nature of the binder/lubricant account greatly for the differences in the results but the concentration of lubricant plays a major role in order to achieve high green properties. However, one surprising result regarding the HD mix is that his cutting forces are lower than the ones of the REF mix even though the HD lubricant is used in a smaller concentration (0.58%-wt for HD mix compared to 0.75%-wt for the EBS lubricant).This is explained by the lower density of the REF mix (7.18 g/cm^3 for the REF mix compared to 7.26 g/cm^3 for the HD mix) and by the better lubricating properties of the HD mix compared to those of the REF mix.

Table 3 shows considerable differences between the HGS as pressed and the HGS once cured. These results highlight the importance of doing the curing treatment to get good green properties. Indeed, the treatment allows a more even distribution of the lubricant and the formation of a continuous polymeric network, which ends up increasing green strength, improving the lubricating properties, and holding the metallic particles during machining which ultimately lowers the breakouts width. The significantly better surface finish observed in table 3 both with the HGS cured and the WP can be explained by the ability of the polymeric binder/lubricant to flow between particles and create the polymeric network either during the compaction at higher temperature (WP) or during the curing treatment (HGS cured).

Concerning the surface finish, the results show that the REF mix has the widest breakouts while the HGS cured mix has the thinnest ones. According to the green strength and the cutting forces measurements, it appears that both high green strength and good lubricating properties promote a better surface finish. Additionally, polymeric binder/lubricants seam to improve surface finish considerably. Indeed, the HD mix and the WP mix have about the same green strength yet the average breakouts width of the latter is much smaller. While the green strength obtained with the HD mix could be attributed mainly to mechanical interlocking and cold welding between particles due to the lower amount of admixed lubricant, the high green strength obtained with the WP mix comes both from mechanical bonds and the polymeric network created during compaction. This polymeric network seems to have the best effect on the reduction of the formation of large breakouts.

The method offering the best machinability among the ones studied in this paper would be the HGS cured mix. This technique is the one allowing the formation of the smallest breakouts. The high green strength and the lubricating properties are the main characteristics accountable for this good machinability. The only inconvenient with this technique is the curing treatment required and its impact on productivity. To assuage this diminution in productivity, the warm compaction (WP) can turn out to be a very good alternative. The breakouts width of the WP mix is slightly higher (~20%) than the ones of the HGS cured mix but the fact that the polymeric network is created during compaction eliminate the need for further time and energy consuming treatments and can make up for the slight deterioration of the surface finish. As for the HD mix, it presented good results given the fact that the lubricant used for this mix does not have binding properties. Notwithstanding these good results, the polymeric network appears to be a requisite for one to maximize the quality of the surface finish.

Conclusion

This study characterized several ways of using binder/lubricants to improve green machining. Results showed that high green strength and good lubricating properties are the key to improve green machining performance. On top of that, special attention has to be paid to the amount of binder/lubricant used since it has a significant impact on green strength and the cutting forces. In addition, the use of a binder/lubricant and the formation a polymeric network appears to have a major influence on the average width of breakouts. In this regard, the methods that provide the best results are the HGS cured and the WP. Results showed that the best surface finish was obtained when using the HGS cured. However, the curing treatment required by this method has an impairing effect on productivity. A good alternative to this method is the warm compaction since it does not require any treatments other the one carried out during the compaction and results showed that it has a very good green machinability.

References

1. R. Causton, C. Schade, *"Machinability: a material property or process response?"*, Advances in Powder Metallurgy & Particulate Materials, MPIF, 2003, part 7, pp. 154-159.

2. R. M. German, *"Powder Metallurgy & Particulate Materials Processing"*, MPIF, Princeton, 2005, 528 pages.

3. B. Tougas, *"Contribution à l'amélioration de l'usinabilité des pièces fabriquées par métallurgie des poudres à l'aide de particules de deuxième phase"*, M. Sc. thesis, Université Laval, in press.

4. J. S. Agapiou, M. F. DeVries, *"Machinability of Powder Metallurgy Materials"*, International Journal of Powder Metallurgy, Vol. 24, no. 1, 1988, pp. 47-57.

5. C. Blais, G. L'Espérance, I. Bourgeois, *"Characterisation of Machinability of Sintered Steels during Drilling Operations"*, Powder Metallurgy, Vol. 44, no. 1, 2001, pp.67-76.

6. J. Campbell-Tremblay, C. Blais, G. L'Espérance, P. Boilard, *"Characterization of the Fatigue Performance of P/M Components Produced with Powders Developed for Improved Machinability"*, Advances in Powder Metallurgy and Particulate Materials, MPIF, 2005.

7. D. S. Madan, *"Effect of Manganese Sulfide (MnS) on Properties of High Performance P/M Alloys and Applications"*, Advances in Powder Metallurgy and Particulate Materials, MPIF, 1992, Vol. 4, pp. 245-267.

8. E. M. Trent, P. K. Wright, *"Metal Cutting"*, Elsevier, Woburn, 2000, 4th Ed., 446 pages.

9. L. Jiang, K. Cui, H. Hänninen, *"Effect of the Composition, Shape Factor and Area Fraction of Sulfide Inclusions on the Machinability of Re-Sulfurized Free-Machining Steel"*, Journal of Materials Processing Technology, Vol. 58, 1996, pp. 160-165.

10. R. Causton, T. Chimino, *"Machinability of P/M Steels"*, ASM Handbook, Vol. 7, Powder Metal Technologies and Applications, ASM, 2002, pp. 671-679.

11. E. Robert-Perron, *"Caractérisation des propriétés mécaniques de pièces fabriquées par métallurgie des poudres ayant subi une opération d'usinage à cru"*, Ph. D. thesis, Université Laval, 2007.

12. Metal Powder Industries Federation, *"Materials Standards for P/M Structural Parts"*, Princeton, 1997.

13. E. Robert-Perron, C. Blais, S. Pelletier, Y. Thomas *"Role Binder/Lubricants in Green Machining"*, Advances in Powder Metallurgy and Particulate Materials, MPIF, 2007.