GREEN MACHINING
FOR CONVENTIONAL P/M PROCESSES

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ABSTRACT

Green machining of P/M parts has been actively studied in recent years. The advantages have been well recognized, including longer cutting tool life and the ability to make complex parts out of sinter-hardenable powders. The high green strength of the compacted parts also prevents green cracks and damages from handling.

With all these advantages, green machining is yet to be widely used in P/M processes since the required high green strength (in excess of about 3000 psi / 21 MPa) cannot be readily obtained through conventional P/M techniques. So far, most green machining operations have been limited to warm compacted parts.

At QMP, this limitation is being removed with a newly developed high green strength (HGS) polymeric lubricant. One distinguished characteristic of this lubricant is its response to temperature. High green strength can be obtained at a compacting temperature of ~55°C, which can be easily reached throughout a green part by cold compaction. Even higher green strength up to ~7000 psi (48 MPa) can be reached by a subsequent curing process for parts pressed to density of 6.8 g/cm^3. This high green strength has made green machining possible for those parts fabricated through conventional P/M processes.

This paper presents the results of green machining tests performed on several timing sprockets. The material used was a sinter-hardenable powder mix of QMP ATOMET 4601 and the HGS lubricant. The sprockets were pressed to a density of ~6.8 g/cm^3 by cold compaction. Green machining (turning a groove along the middle of the teeth) was performed on as-compacted and on cured parts. Results have shown that the HGS lubricant provides sufficient green strength for clamping and machining operations, especially after curing. The machined surfaces appeared to be smooth and the edges remained integrated. The green-machined sprockets made of sinter-hardenable powder eliminated heat treatment, providing much longer tool life and improved size tolerances.

I. Introduction

In recent years sinter-hardening powders have been widely used in P/M parts to eliminate heat treatment operations. Very high hardness can be obtained after sinter-hardening. However, this high hardness made subsequent machining very difficult. This problem prevented sinter-hardening materials from being used on parts where a secondary machining is required.

A typical example is the timing sprocket shown in Figure 1. This part has a groove at the middle of the teeth, which has to be formed by a secondary machining. Traditionally, this type of part was processed with the following procedures: compacting → sintering → groove turning (plunge cut) → heat treatment → honing. For good machinability, powders of medium carbon content are usually selected and free machining aids (e.g. MnS) are usually added in the mix. Typical problems with this process have been well recognized, including quick cutting tool wear, frequent cutting tool change and adjustment, heat treatment distortion, discoloring, etc.

Figure 1. Typical Timing Sprocket.

Green machining provides the possibility of making this type of part from sinter-hardenable materials. Because the particles are not metallurgically bonded, the unsintered parts can be machined with little force. However, green strength has to be high enough (>3000 psi / 21 MPa) to survive the clamping and machining stress.[1] This high green strength cannot be easily obtained through conventional P/M techniques. Most of the green machining tests so far were conducted on warm compacted parts.

A new polymeric lubricant, was recently introduced by QMP. Unlike traditional waxes and metallic stearates, this lubricant significantly enhances green strength when added into powder mix.[2,3] For example, green strength can be two times higher compared to EBS wax when compacting at a temperature of 55°C. Semi-production trials have proven that this temperature could be easily reached throughout a green part by cold compaction. Even higher green strength can be given through a subsequent curing process - up to

7000 psi (48 MPa) at a density of 6.8 g/cm^3. The high green strength provided by this lubricant makes green machining possible for conventional P/M process.

This paper presents green machining results performed on timing sprockets made of sinter-hardenable powders and high green strength (HGS) polymeric lubricant.

II. Experimental Procedure

During this study, a QMP 4601 HGS sinter-hardenable mix was tested. This mix was prepared from ATOMET 4601, 2.5 wt% Cu, and 0.9 wt% graphite as well as 0.65 wt% HGS lubricant..

The sample sprockets were pressed to a bulk green density of 6.7-6.8 g/cm^3 with a 200 ton mechanical press from Yoshizuka. Considering the thermal response of the HGS lubricant, the compact tools (die, punches and core rod) were warmed up by compacting 10 parts prior to making samples.

These compacted samples were separated into 3 groups: the 1st group of parts remained as-compacted; the 2nd group were cured in air for 1h at 190^{o}C through a tempering furnace; and the 3rd group was pre-sintered at 815….?^{o}C in endothermic atmosphere through a conventional mesh belt furnace.

A fixture was made to hold the sprocket for the machining test (Figure 2). The sprocket was held on the outer diameter of the steel bar by a side plate and a bolt, which can be tightened to the steel bar. The cutting tool was PVD coated WC insert (model UCPA 3196 grade 905) from Valenite, sitting on a holder.

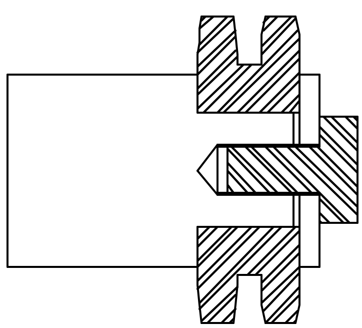


Figure 2. Sample Holder and Cutter.

The samples were machined at different turning speeds and feed rates. High-speed machining tests were performed at Tru-die Ltd. with a CNC lathe, model LB300 from Okuma. Low-speed machining tests were performed on a Hardinge AHC lathe. The machining conditions are given in Table 1. Turning speed varied from 300 to 3800 rpm and a feed rate from 0.01 to 0.30 mm/rev. The capability of machining the green parts was determined by examining both the structural integrity as well as the surface finish of the machined grooves.

Table 1. Machine settings for green machining tests

No	Speed (rpm)	Feed rate (mm/rev)	As-compacted	Cured	Pre-sintered
1	300	0.125	X	X	X
2	750	0.07	X	X	X
3	750	0.15	X	X	X
4	750	0.21	--	X	--
5	750	0.30	--	X	--
6	900	0.20	X	X	X
7	1000	0.02	X	X	--
8	1200	0.07	X	X	--
9	2000	0.02	--	X	--
10	2000	0.03	--	X	--
11	2000	0.075	X	X	--
12	2000	0.125	--	X	--
13	3000	0.02	--	X	--
14	3000	0.075	--	X	--
15	3000	0.03	--	X	--
16	3800	0.01	--	X	--
17	3800	0.02	--	X	--
18	3800	0.03	--	X	--

Note: all samples were cut without fluids excluding #1.

Several sprockets were produced using optimum green machining conditions on a semi-production scale. These parts were sintered in endothermic gas through an Abbott sintering furnace at 2050°F for ~30 minutes with a varicool setting at 60Hz and then tempered through an Abbott tempering furnace. The part integrity, surface finish of the cutting grooves, tool wear as well as mechanical properties of the parts containing HGS were compared with sprockets made of FN-0205 powder through traditional processes, i.e. sintering → machining → carburizing.

III. Results & Discussion

A) Machining tests

The capability of as-compacted, cured and pre-sintered sprockets containing the HGS lubricant system to withstand green machining was compared using different machining setting conditions; turning speeds and feed rates. This comparison was achieved by examining the structural integrity as well as the surface finish of the cutting grooves of the sprockets.

Results clearly show that the as-compacted and the cured parts did not survive the machining test with setting conditions typically used for sintered parts, i.e. with a turning speed of 300 rpm and a feed rate of 0.125 mm/rev. Indeed, some broken teeth were found for all these parts. Only the pre-sintered samples survived the machining test without a broken tooth. However, it is worth mentioning that chipping was still found on these parts at the edge where cutting tool exited the tooth (referred to as "exit edge"), and burrs were also observed along the machined edges at tooth root.

The adjustment of the turning speed and feed rate significantly improved the integrity and surface finish of the machined grooves of all the parts, as shown in Figure 3. Indeed, the as-compacted parts exhibit less damage on the teeth by using a turning speed of 750 rpm and a feed rate of 0.07 mm/rev, though broken teeth were still seen (Figure 3a). The cured parts survived the machining test without any broken teeth (Figures 3b). The pre-sintered parts also gave smooth and shining machined surfaces with no broken teeth (Figure 3c). However, it is clear that the part integrity and surface finish were still not optimized in these conditions. For instance, the machined surface was rough with some tiny pits on the cured parts, while chipping still existed at the exit edge of the teeth for all parts.

(a) (b) (c)

Figure 3. Surface finish of green machined parts at turning speed of 750 rpm and feed rate of 0.07 mm/rev. (a) As-Compacted, (b) Cured and (c) Pre-Sintered

Considerable improvement was seen on the as-compacted and cured parts when machining speed further increased to 900 rpm even by using a relatively high feed rate of 0.20 mm/rev. No broken teeth were found under these conditions. In general, the machined surface became smooth with a limited amount of tiny pits (Figure 4). Only slight chipping was noticed along the machined edges of the teeth. Increasing the turning speed from 1000-1200 rpm to 3800 rpm and by keeping a relatively slow feed rate (0.02-0.07 mm/rev) did not further improve the quality of the machined surface of both the as-compacted and cured parts. One possible reason for this is that the machine became unstable under high speeds.

Figure 4. Surface finish of green machined parts at tuning speed of 900 rpm and feed rate 0.2mm/rev.

Nevertheless, it is worth mentioning that the cured parts still exhibited a smoother surface finish as compared to the as-compacted parts by using a turning speed and a feed rate of 900 rpm and 0.20 mm/rev, respectively. This indicates that the higher green strength from the curing process has made green machining more robust. As already reported, the HGS system has the ability to flow through the porosity during the curing treatment and create a strong continuous polymeric network that further strengthens green parts and improves machining capability.[2]

The effect of feed rate on the green machined surface was also studied. In general, slower feed rate gives smoother machined surface and less chipping along the exit edges. However, this tendency was changed when the feed rate was reduced to 0.02 mm/rev. Slower feed rates result in rougher, instead of smoother surface finish and an increased temperature of the machined parts.

Based on the above observations, it is realized that a minimum turning speed is necessary for green machining. Higher turning speed and slower feed rate are usually beneficial for green machined surfaces, although limits exist for both parameters. Satisfactory green machining can only be obtained with a proper combination of turning and feed rate, which gives a process window as shown in Figure 5.

Finally, it is worth noting that there exist advantages of machining cured instead of pre-sintered parts. A simple curing treatment in air at a relatively low temperature is obviously not as expensive as a pre-sintering treatment. Also, it is apparent that the noise from the interrupted machining was more pronounced with pre-sintered or sintered parts. This is mainly due to the stronger bounds created between particles as compared to those resulting from a curing treatment. The chips appeared as flaky loose powder for cured parts, while pre-sintered or sintered parts typically produced coarse, heavily work-hardened, fully dense chips.

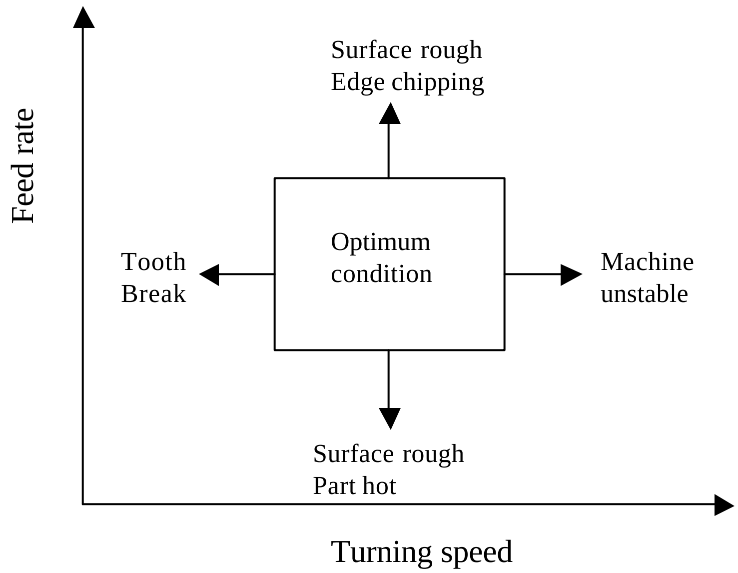

Figure 5. Processing window for green machining operation.

B) Application of Green Machining to Production

Further studies were conducted through semi-production trials at Sinteris. The powder compositions were adjusted to fit the existing tooling developed to press parts of FN-0205. Results confirmed that satisfactory green machining could be achieved by optimum machining settings, especially on cured parts. The part integrity was maintained while satisfactory machined surface finish was obtained during testing. The surface finish of the grooves only exhibited a limited amount of tiny pits. Considering the service conditions of the timing sprocket, this surface finish still meets the part function requirements since the surface inside the groove is not critical if the edge integrity of the teeth is maintained during machining.

The green machined sprockets were also sintered and tempered in this study. The properties of these parts were compared to those parts made of FN-0205 powder through traditional processes (i.e., sintering → machining → carburizing). It was found that the parts from both processes have comparable hardness (~30 HRC) and crush strength (~6000 lbs tooth break strength), and both parts passed functional tests.

However, it is worth noting that the green machined parts still exhibited several distinguished advantages compared to the traditional process. For example:

(1) Longer cutting tool life was obtained with the new process involving green machining operation. With this technique, one cutting edge has finished more than 10,000 grooves without showing any hint of damage as compared to only ~120 grooves with the traditional process. Considering that one cutting edge can be reshaped twice, a total of only 360 sprockets can be finished with one cutting edge through the

traditional process. The down time of green machining operation was then reduced to nearly zero compared to frequent cutting tool change and adjustment of the traditional process. The green machining process also eliminated cutting fluids.

(2) Green machined sinter-hardenable parts eliminated heat treatment operation except tempering. The finished parts have better size tolerance and favorable appearance.

(3) With the traditional process, burrs formed along the machined edges during machining operation. These burrs are difficult to remove because of their locations. A sizing operation had been used following machining to remove the burrs. This operation is no longer necessary for the green machined sprockets since no burrs formed along the machined edges.

(4) Although material cost for sinter hardening powder is higher and a curing operation was added to the process, the overall cost of manufacturing FLC-4708HGS sprockets was still reduced through green machining by about $0.11US per piece as compared to those made of FN-0205 through conventional processes. More cost savings could be obtained if the green machined chips (flakes) were recycled, which is still under study.

Therefore, from the above results, it is clear that green machining is a very attractive process to improve tool life, increase productivity and also promote competitiveness. This technique will be entered into production at Sinteris Inc. to commercialize several sprockets with similar shapes (Figure 6).

Figure 6. Green machined sprockets in production.

IV. Conclusions

(1) The QMP HGS lubricant system provides sufficient green strength for clamping and green machining of sprockets made of a sinter-hardening powder through conventional P/M processes.
(2) Surface finish and edge integrity of the green machined sprockets can be significantly improved by adding a curing process to the as-compacted parts.
(3) A minimum cutting speed is required for green machining. Satisfactory machining results can be obtained through a proper combination of turning speed and feed rate.
(4) Parts made of sinter-hardenable powders through green machining eliminate heat treatment, give better size tolerance, favorable appearance and significant cost saving.

V. Acknowledgment

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VI. References

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