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Improving Green Strength to Enable Green Machining

François Chagnon, Linda Tremblay and Sylvain St-Laurent
Quebec Metal Powders LTD

Martin Gagné
Rio Tinto Iron And Titanium-Technology

ABSTRACT

Although powder metallurgy (P/M) is a cost attractive route to manufacture near net shape complex parts, many P/M components require machining to meet tight dimensional tolerances or accommodate design features that cannot be molded during compaction. With the development of high performance materials having high strength and apparent hardness in the as-sintered condition, green machining is becoming an important issue to maintain the competitiveness or extend the use of P/M technology. Machining of green P/M parts can be made feasible if the strength of the part is high enough to enable the clamping and machining of the component. Therefore, the use of specific techniques to improve strength and allow machining of un-sintered P/M parts are worthy avenues to reduce machining costs. This paper describes various routes that increase green strength of P/M components and make feasible green machining.

INTRODUCTION

Powder metallurgy is a cost attractive route to produce near net shape complex parts. High strength parts can be manufactured by using new high performance materials and advanced shaping techniques. However, many of these new P/M components require machining to meet tight tolerances or accommodate design features that cannot be molded into a part. Because these parts exhibit high hardness and strength after sintering, it becomes more difficult to machine features that cannot be molded at the compaction step.

In order to reduce the machining costs, it would be advantageous for the P/M industry to machine parts before sintering if their strength is sufficiently high to enable the clamping and machining of the components. However, the addition of lubricant to powder mixes which is required to eject parts at the end of the compaction cycle is an obstacle to the green machining route. Lubricants commonly used in P/M are generally known to reduce green strength [1, 2]. Also, as the compacting pressure is increased, a high concentration of lubricant limits the maximum achievable green density [3]. Several studies have been carried out during the last decade to characterize and/or develop new lubricant systems that could improve both the compressibility and green strength [4, 5, 6].

This paper describes various techniques and processes that can be used to achieve adequate strength to enable the machining of un-sintered P/M parts and hence reduce machining costs.

EXPERIMENTAL PROCEDURE

Table 1 gives a description of the various materials and compaction conditions used in this study. Green properties were determined using standard TRS (transverse rupture strength) specimens.

Machinability characterization was carried out using a drilling set-up consisting of a high power press drill equipped with an automatic feed rate control and a specimen holder capable of monitoring the torque on the tool and the thrust force transmitted to the test piece. A detailed description of this set-up is given elsewhere [7]. Rectangular specimens of 31.8 mm in length, 12.7 mm in width and 12.7 mm in thickness were used for this characterization. The feed rate and the cutting speed were respectively 0.20 mm/rev. and 3420 RPM. The cutting tools were black oxide coated high speed steel drills with a helix angle of 118° and a diameter of 6.35 mm. The machinability was characterized by evaluating the breakout as the drill exited the holes.

CONVENTIONAL P/M PROCESS

Figure 1 illustrates a conventional P/M process flow diagram for standard lubricants such as EBS waxes, metallic stearates or mixtures of both. Table 2 gives the typical green properties of TRS specimens made from a F-0005 mix containing EBS wax compacted to a green density of 7.10 g/cm^3. Specimens containing a concentration of 0.75% wax show a green strength of 18.3 MPa. As illustrated in Figure 2, a significant breakout measuring about 2 mm is observed as the drill

TABLE 1. Description of the Materials and Compaction Conditions.

Mix	Base Powder	Lubricant, %	Lubricant type	Compaction	Density, g/cm³
F-0005	ATOMET 1001	0.75	EBS wax	Cold pressed	7.10
F-0005	ATOMET 1001	0.75	Polymeric	Cold pressed	7.10
FN-0205	ATOMET 1001	0.60	Warm pressing	Warm compacted	7.00-7.35
FLN4-4405	ATOMET 4401	0.50	EBS wax	Double pressed	7.30-7.42
2% Cu-0.90% graphite	ATOMET 4701	0.75	EBS wax	Cold pressed	6.8

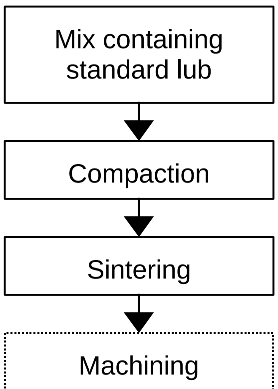


Figure 1. Typical Flow Diagram of a Conventional P/M Process Using Standard Lubricants.

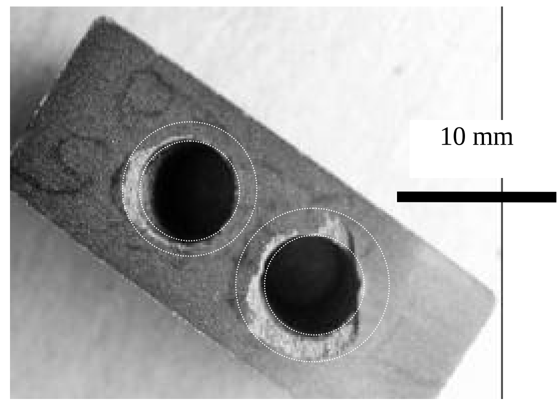


Figure 2. Breakout as the Drill Exited a Specimen Made from a F-0005 Mix Containing 0.75% Wax and Pressed to a Density of 7.10 g/cm³.

exited the specimen. Therefore, green parts made from mixes containing conventional lubricants are not candidates for machining in the green condition; these parts must be sintered to increase their strength prior to machining. This may however result in machining difficulties if the sintered parts exhibit high strength and apparent hardness.

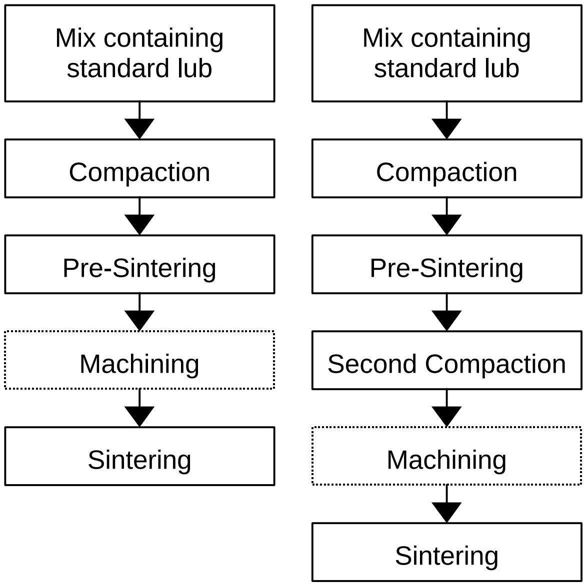
TABLE 2. Green Characteristics of F-0005 Specimens Containing 0.75% EBS Wax.

Compacting Pressure, MPa	586
Green Density, g/cm³	7.10
Green Strength, MPa	18.3

PRE-SINTERING

Sinter hardenable parts can be pre-sintered to allow machining before sintering. Figure 3a presents a flow diagram of this process. It is intended for materials having apparent hardness of 30 HRC or more after sintering. This high hardness significantly reduces the machinability of such materials. As illustrated in Figure 4, pre-sintering significantly increases the strength of sinter hardenable materials, even at a density of 6.8 g/cm³. The partial diffusion of the added graphite in the iron particles allows the formation of a pearlite/ferrite structure and, therefore, an improved surface finish. In a previous study, a pre-sintering temperature around 810°C was optimum to form the minimum amount of pearlite required to obtain an acceptable surface finish of the machined specimens [8].

Figure 5 illustrates the breakout as the drill exited a specimen made from ATOMET 4701 admixed with 0.9% graphite and 2% copper pressed to a density of 6.8 g/cm³ and pre-sintered 28 minutes at 810°C under a 90% nitrogen based atmosphere. The breakout is significantly reduced as compared to the F-0005 reference material in the green stage although the density is 0.3 g/cm³ lower.



a b

Figure 3. Flow Diagrams of Processes where Machining Can Be Carried Out after a Pre-Sintering Operation.

a) Sinter Hardening
b) DPDS

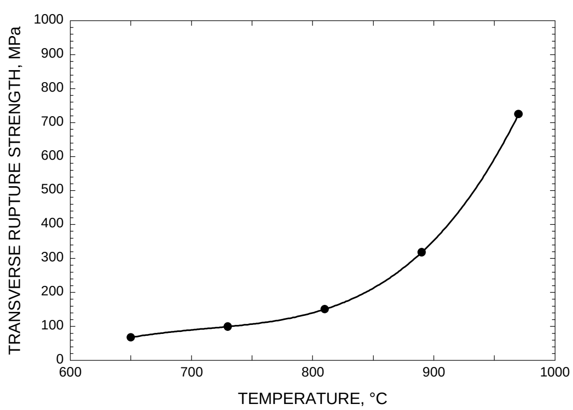
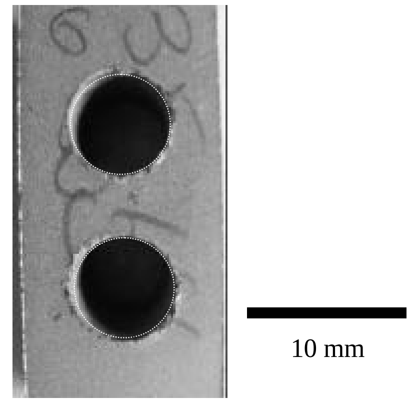


Figure 4. Effect of Pre-Sintering Temperature on the Strength of Specimens Pressed to 6.8 g/cm³ (ATOMET 4701+0.9% graphite+2% copper).

The double press/double sinter process (DPDS) is frequently used in P/M to increase the density and hence the mechanical properties of structural parts. Pre-sintering is primarily used to burn off the lubricant and recrystallize the iron particles to allow densification during the second compaction of the DPDS process. However, some metallurgical bonds are also created during this operation and increase the strength of the components. Figure 3b shows a flow diagram of this process in which a machining operation can be included before sintering.

Figure 5. Breakout as the Drill Exited a Specimen



Made with ATOMET 4701+0.90% Graphite+2% Copper+0.75% Wax Pressed to 6.8 g/cm³ and Pre-Sintered 28 Minutes at 810°C.

As illustrated in Figure 6, the specimens exhibit high enough strength to allow machining after the second pressing. However, the pre-sintering temperature must be controlled to optimize the densification. Pre-sintering above 730°C results in strength exceeding 200 MPa. This is however obtained to the detriment of density due to the onset of graphite diffusion at about 760°C. Nevertheless, a strength of 150 MPa is sufficient to allow machining before the sintering step.

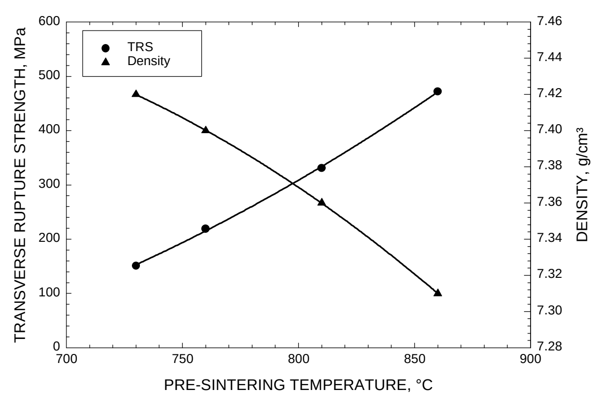


Figure 6. Strength and Density of FLN4-4405 Specimens After Pressing at 690 MPa and Re-Pressing at 690 MPa Vs Pre-Sintering Temperature.

WARM COMPACTION

Warm compaction is a process where a pre-heated powder mix is pressed in a heated die at a temperature usually ranging from 100 to 150°C depending on the size of components. This results in an increased density, typically 0.10 to 0.20 g/cm³ higher than the one achieved at room temperature for a similar compacting pressure [9, 10, 11]. The discontinuous distribution of a thin film of lubricant within the compact improves the metal-to-metal contact and hence the interparticle bonding. This results in higher green strength as compared to specimens pressed at room temperature [9, 12].

A typical flow diagram of the warm pressing process is presented in Figure 7. The higher green strength achieved with this process makes machining feasible in the green stage.

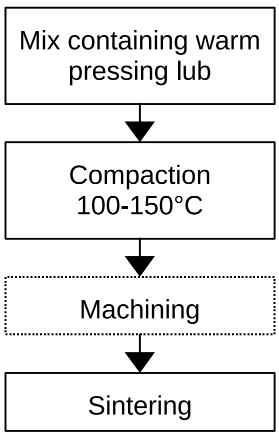


Figure 7. Typical Flow Diagram of the Warm Compaction Process.

Figure 8 illustrates the gains in density and strength achieved when compacting FN-0205 specimens containing 0.6% lubricant at 130°C. At 25°C, green strength increases from 12.4 to 17.9 MPa as the compacting pressure is raised from 414 to 690 MPa. As already illustrated in Figure 2, this level of green strength is not sufficient to machine specimens in the green stage even if the density is raised from 6.80 to 7.18 g/cm³. Raising the temperature from 25 to 130°C increases both the density and the green strength. However, the effect is more evident for green strength which increases by a factor of 2.7 to 3 for the higher compacting temperature because of the formation of metallurgical bonds between particles. Green strength values beyond 35 MPa make machining feasible before the sintering operation. As illustrated in Figure 9, there is almost no breakout when drilling holes in FN-0205 specimens warm pressed at 690 MPa and 130°C.

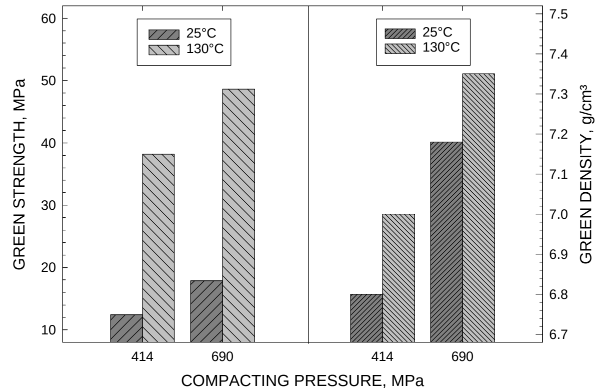


Figure 8. Effect of Compacting Pressure and Temperature on Green strength and Green Density (Specimens Pressed from FN-0205 mixes containing 0.6% Lubricant).

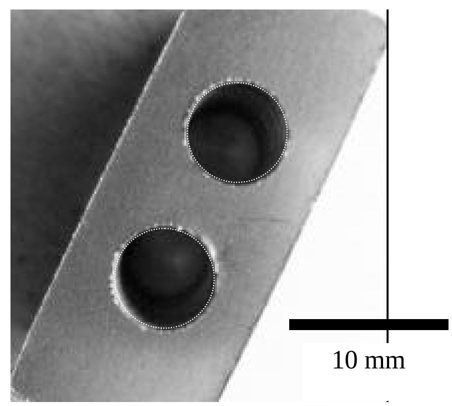


Figure 9. Breakout as the Drill Exited a Specimen Made from a FN-0205 Mix Pressed at 690 MPa and 130°C (Green Density; 7.35 g/cm³).

NEW POLYMERIC LUBRICANTS

The development of new polymeric materials combining improved mechanical properties with good lubricating characteristics makes possible the achievement of high green strength by cold pressing powder mixes. Figure 10 illustrates two routes that can be followed to improve the green strength of P/M parts by using such materials. In the first diagram, a green strength enhancing lubricant is admixed to the powder mix which is cold pressed while in the second, a modified system can reach very high green strength after cold compaction and heat treating at a temperature below 200°C. Figure 11 compares the green strengths achieved with specimens made from F-0005 mixes containing 0.75% of these special lubricants pressed to a density of 7.10 g/cm³. The green strength achieved with specimens containing EBS wax is also given for comparison. For processing route A, specimens pressed to a green density of 7.10 g/cm³ show a strength of 38 MPa, which is two times greater than that of a similar mix containing 0.75% EBS wax. With the processing route B, the use of a modified

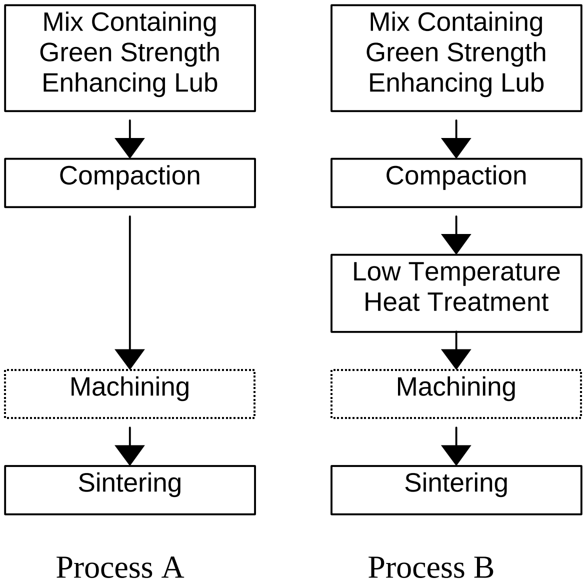


Figure 10. Flow Diagrams Illustrating the Machining Operation with High Green Strength Materials.

version of this lubricant system followed by a heat treatment at low temperature enables a cross-link of the lubricant system and achieves a strength exceeding 90 MPa. For both processing routes, the green strength is high enough to enable green machining. This is well illustrated in Figure 12, where the breakout is almost eliminated for both systems when compared to the reference F-0005 material (Figure 2).

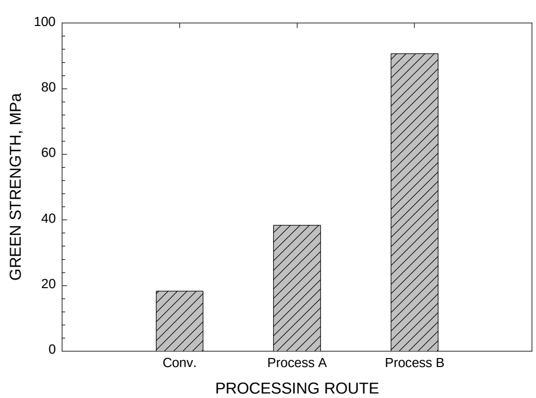


Figure 11. Green Strength of Specimens Pressed to 7.10 g/cm³ (F-0005 Mixes Containing 0.75% Lubricant).
Conv.: EBS wax.
Process A: Without Heat Treatment.
Process B: With Low Temperature Heat Treatment.

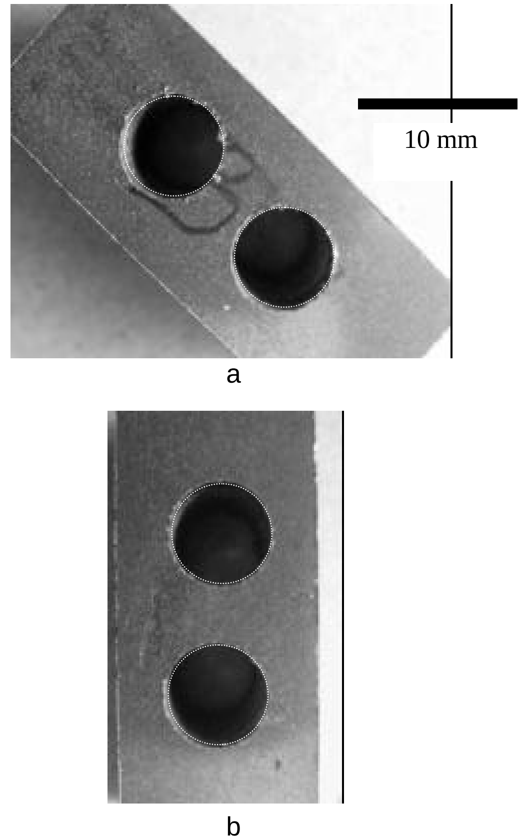


Figure 12. Breakout as the Drill Exited a Specimens Made from a F-0005 Mix Containing 0.75% Green Strength Enhancing Lubricants Pressed to a Density of 7.10 g/cm³;
a) Without Heat Treatment.
b) With a Heat Treatment.

CONCLUSIONS

- Parts made from mixes containing standard P/M lubricants cannot be green machined because of their low green strength.
- For parts exhibiting high apparent hardness after sintering such as sinter hardening materials, a pre-sintering treatment at about 810°C can be used to increase strength and allow machining before sintering.
- The DPDS process significantly increases green strength of P/M parts. Machining can be carried out after the pre-sintering and re-pressing stages.
- Warm pressing increases green strength and is an alternate route to enable machining in the green state.
- The development of new polymeric lubricant systems makes possible to reach high green strength after cold compaction. This will make green machining a cost effective way to reduce machining costs of P/M materials.

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