CHARACTERIZING THE MACHINABILITY OF GREEN P/M PARTS

by

Martin Gagné
Rio Tinto Iron & Titanium Inc.
and
François Chagnon
Quebec Metal Powders ltd.
Tracy, Québec, Canada

ABSTRACT

In most manufacturing processes including powder metallurgy, machining is widely used for the final shaping of parts and often represents a significant fraction of the cost of the finished component. Therefore improving the machinability of structural parts has a significant impact on the fabrication cost and competitiveness of a manufacturing process itself.

Admixing of machinability promoters such as BN and MnS is the most widely used technique by the P/M industry to improve the machinability of powder metal components. However, performing the machining operations in the green state would be an alternate route to improve the machinability of P/M parts. The development of lubricants and/or processes that insure the high as-compacted strength required to maintain the physical integrity of the parts makes green machining an attractive process. In this paper, the behavior of green P/M specimens during machining is described. The various machinability indices generated during a drilling test are related to the characteristics of the drilled holes and the key factors for successful green machining are discussed.

INTRODUCTION

All metal cutting operations are likened to a fundamental process in which a wedge-shaped tool with a straight cutting edge is constrained to move relative to the workpiece in such a way that a layer of material is removed in the form of a chip(1). The formation of chips involves the occurrence of a primary deformation zone at the base of the chip where a continuous shearing action persists and of a secondary deformation occuring between the tool and the chip. Although these mechanisms are applicable to all materials, the stresses required to form the chips are strongly dependent on the physical and structural characteristics of a material. Cast irons, for example, machine better than conventional steels due to the lubricating and chip breaking effects of graphite particles(2). On the other hand, another example is P/M materials whose machinability is impaired by the presence of pores(3); for these materials, admixing(4) or prealloying(5) with machinability enhancers is needed to make them competitive with ductile iron or machinable steels from a machinability standpoint(6). However, another approach to improve the machinability of P/M materials is to machine them prior to sintering. In such a case the stresses required to drill a hole are reduced by a factor of 5 to 8(3) resulting in a tremendous improvement in tool life. A recent study published by Chagnon et al[7] clearly showed that this approach is appropriate for high green strength materials. In this paper, the machinability of various green P/M materials is characterized in detail using an instrumented drilling test; the response of these materials to more complex shaping operations such as threading was explored.

EXPERIMENTAL PROCEDURES

Materials

Four different materials whose descriptions are given in Table 1 were used in this study. All based on ATOMET 1001 water-atomized steel powder, they exhibit different green strengths and densities that were obtained by changing the lubricant and/or the manufacturing process. Details on the materials and the fabrication processes can be found elsewhere[7,8].

Table 1: Description of the Materials

Identification	Composition	Lubricant	Compaction	Density g/cm^3	Green Strength MPa
A	F-0005	0.75% EBS wax	Cold compaction	7.10	18
B	FN-0205	0.60% warm pressing type	Warm compaction	7.35	52
C	F-0005	0.75% polymeric A	Cold compaction	7.10	38
D	F-0005	0.75% polymeric B	Cold compaction + low temperature treatment	7.10	90

A few warm-pressed specimens were sintered for 30 min. at 1120° C in a 90% nitrogen based atmosphere; these were used as a reference for the machinability evaluation of the green materials.

Machinability Evaluation

Machinability was characterized using an instrumented drilling set-up which is described in detail elsewhere[6]. During the tests which were carried out at a cutting speed of 3420 rpm and feed rates of either 0.08 or 0.20 mm per revolution, the thrust force transmitted to the part and the torque applied on the tool were measured. The cutting tools were black oxide coated high speed steel drills with an helix angle of 118° and a diameter of 6.35 mm. The samples consisted of rectangular specimens measuring 31.8 mm in length, 12.7 mm in width and 12.7 mm in thickness. In addition to these parameters, the machinability evaluation of the materials was completed by the examination of the drilling chips and of the structural integrity and surface finish of the drilled holes.

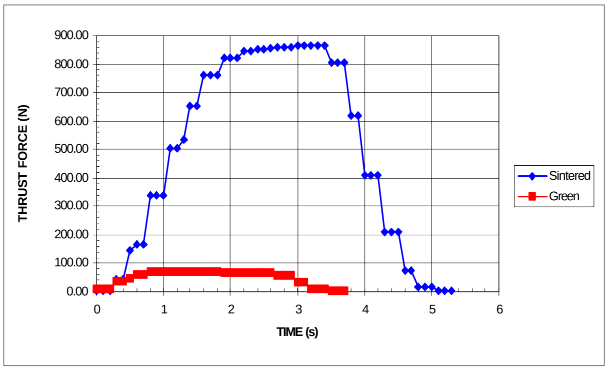
In order to increase the severity of the machining process, a preliminary evaluation of the response of green materials to a threading operation was carried out. Holes were drilled using a "H" drill and 5/16"/18 threads were then made manually. In materials where threading was possible, the surface finish was characterized in the green and sintered [*] conditions. Although the dimensional stability of

[*] Same sintering parameters as previously mentioned.

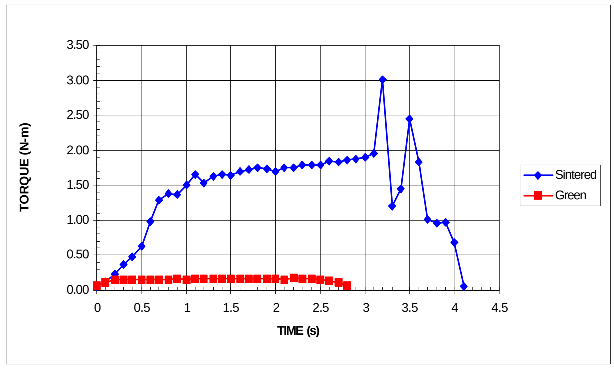
the threaded holes during sintering was not considered in this preliminary study, the fit between the threads and the appropriate bolt was verified.

BENEFITS OF GREEN MACHINING

The main benefit of green machining is the reduction of the cutting stresses and friction at the tool/workpiece interface. As shown in Figure 1, drilling holes in warm-compacted material B generates thrust force and torque which are only about 10% of those measured in the sintered material.



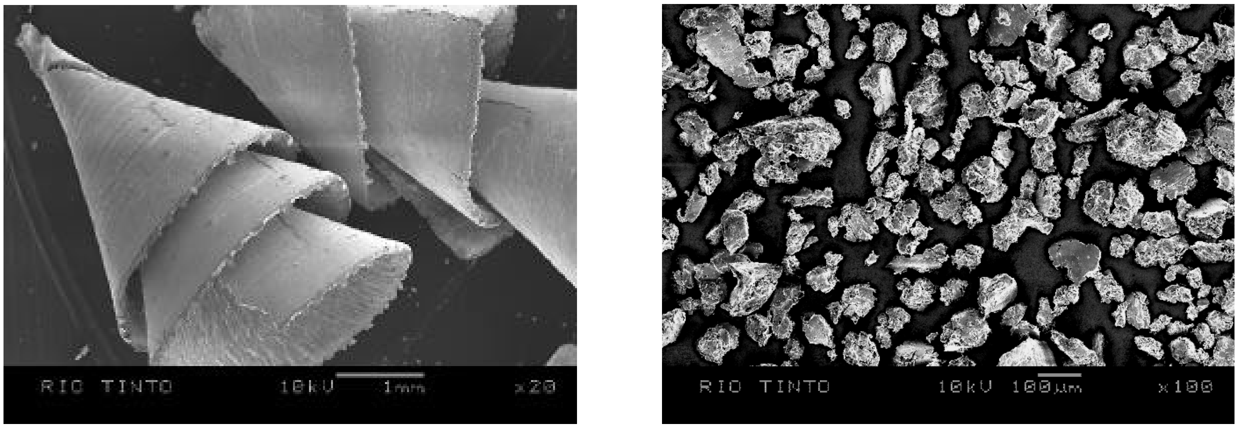
a)



b)

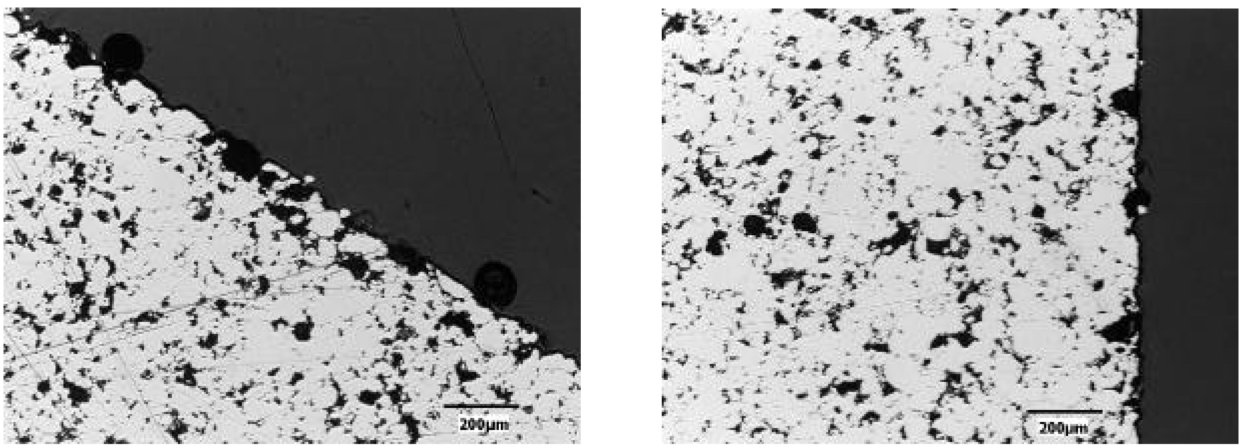
Figure 1. Comparison of a) Thrust Force and b) Torque Measured When drilling in As-Warm-compacted and Sintered Material "B" (3420 rpm, 0.08 mm/rev).

Examination of the chips revealed significant differences due to the cutting mechanisms involved in each case. Drilling in sintered parts produces coarse, heavily work-hardened, fully dense chips as seen in Figure 2a. For the as-warm-compacted parts, the material is removed mainly by breaking the links (either mechanical or metallurgical) between the particles or by cutting the particles. In this case, the machining debris consist of a mixture of "intact" and "cut" particles, Figure 2b. The machining mechanism is further illustrated in Figure 3 which shows the surface of the material after drilling at a speed of 3420 rpm and a feed rate of 0.08 mm per revolution. The extraction of particles results in cavities in the surface under the tool while the cut of the particles leaves a regular surface on the profile of the hole, Figure 3a. However, when drilling, the integrity of the lateral surface of the hole is the prime consideration as the holes are generally drilled through the entire part. As seen in Figure 3b, the lateral surface of the holes drilled in the as-warm-compacted material is significantly smoother than the cut surface shown in Figure 3a due to the densification and surface polishing induced by the drill flute during piercing. By comparing Figures 3a and 4, it is clear that the surface finish of the holes drilled in the sintered material is superior due to the strong inter-particle bonding resulting from the sintering process.



a) b)

Figure 2. Comparison of Chips Obtained When Drilling in a) Sintered and b) As-Warm-Compacted Material "B" (3420 rpm, 0.08 mm/rev).



a) b)

Figure 3. Structure under the Surface a) at the Bottom and b) on the Side of a Hole Drilled in the As-Warm-Compacted Material "B" (3420 rpm, 0.08 mm/rev).

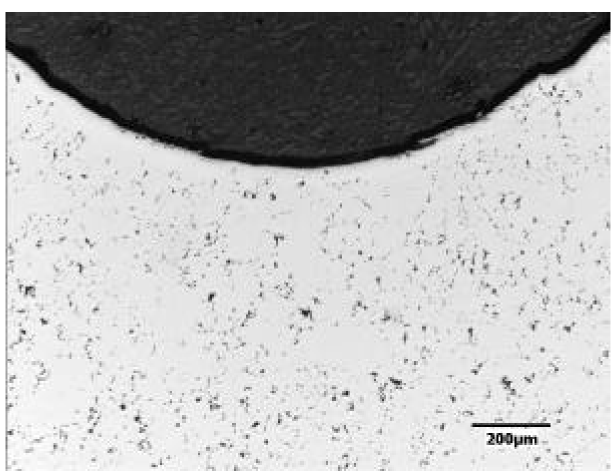
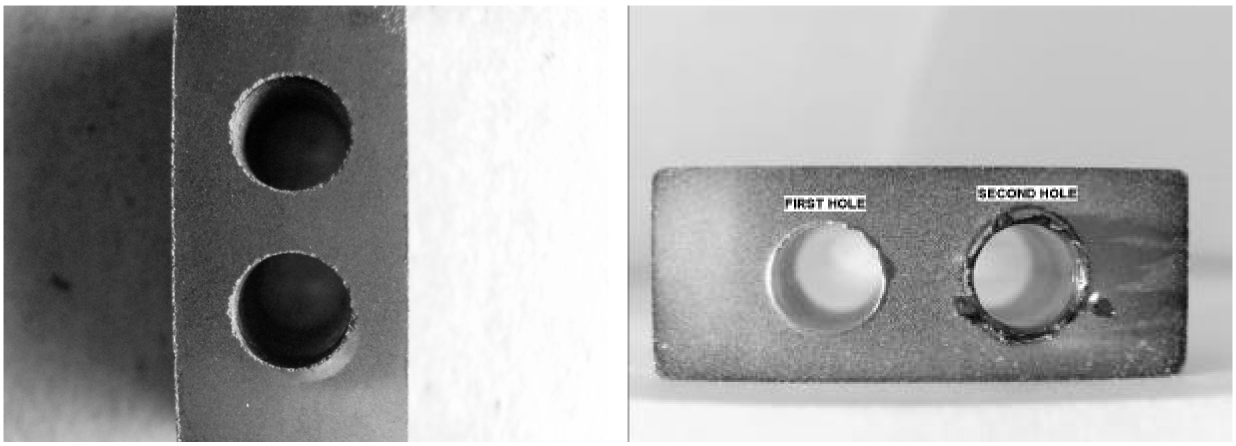


Figure 4. Structure at the Bottom of a Hole Drilled in the Sintered Warm-Compacted Material "B" (3420 rpm, 0.08 mm/rev).

As previously indicated, most of the drilled holes extend through the entire thickness of a part. Therefore, the extent of the damage caused when exiting the part can be used as another index of the machinability of a material. As seen in Figure 5, very little damage is caused to the as-warm pressed material; in the sintered material, burs are seen on the exit surface, Figure 5b, even after the first hole. This phenomenon, observed when drilling in relatively ductile material such as the FN-0205 composition, corresponds to the instability of the torque values seen in Figure 1b.

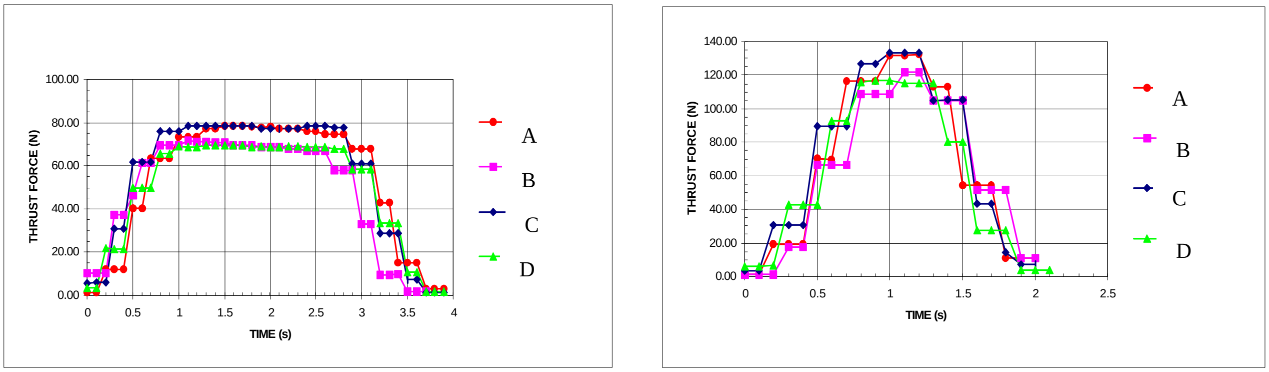


a) b)

Figure 5. Break-out as the Drill Exited the Specimens Made of Material "B" in the a) As-Warm-Compacted and b) Sintered Conditions.

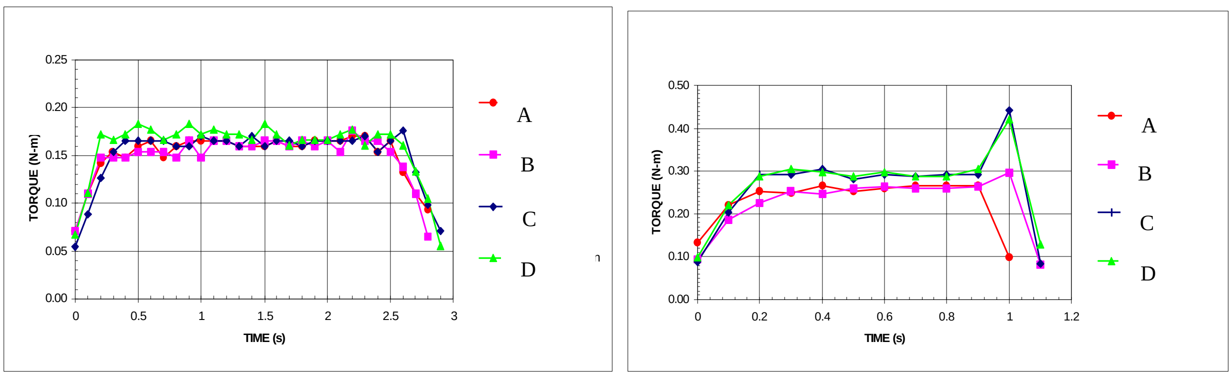
EFFECT OF GREEN STRENGTH ON GREEN MACHINING PARAMETERS

Machinability of the four materials described in Table 1 was compared by drilling tests carried out at a cutting speed of 3420 rpm and feed rates of 0.08 and 0.20 mm/rev. Results are presented in Figures 6 and 7. An increased feed rate is accompanied by higher thrust force and torque values, which, however, remain at very low levels whatever the feed rate. The higher green strength of materials B, C and D did not affect the thrust force values at either feed rates nor the torque when drilling at a low feed rate. However, as seen in Figure 7, when machining at a high feed rate, i.e. 0.20 mm/rev., the torque increases from 0.3 N.m to 0.45 N.m (a 50% increase) as the drill exits the hole of high green strength materials.



a) b)

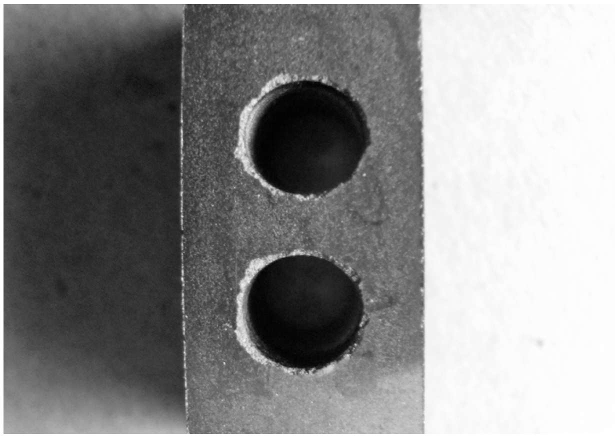
Figures 6. Thrust Force Curves Obtained when Drilling Holes at a) 0.08 mm/rev and b) 0.20 mm/rev in Green Materials with Significantly Different Green Strengths.

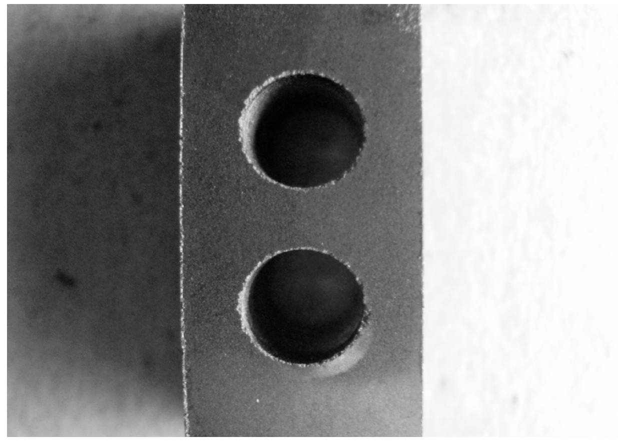


a) b)

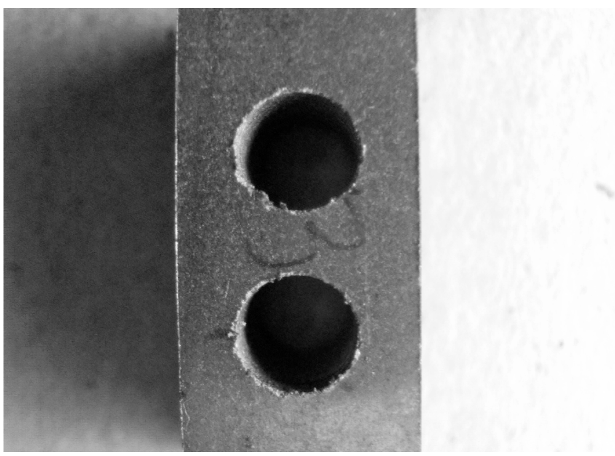
Figure 7. Torque Curves Obtained when Drilling Holes at a) 0.08 mm/rev and b) 0.20 mm/rev in Green Materials with Significantly Different Green Strengths.

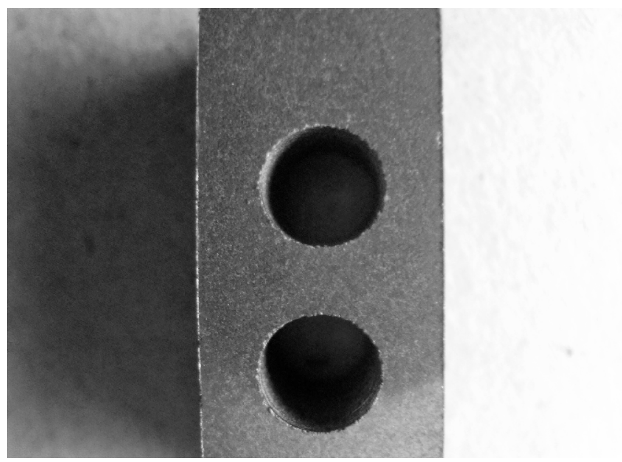
Figures 8 and 9 compare the severity of the break-out observed at the exit of the tool when drilling at a cutting speed of 3420 rpm and feed rates of 0.08 and 0.20 mm per revolution, respectively. At both feed rates, significant break-out occurred in material A as the drill exited; the higher the feed rate the larger the damaged area. Such a low green strength material is inadequate for green machining. For the other materials, minimal damage was observed at the exit of the drilled holes. In the high green strength materials, debris remain attached to the exit surface of the holes which may be easily removed without affecting the surface finish.
Development of a proper holding system would limit such defects.





a) b)

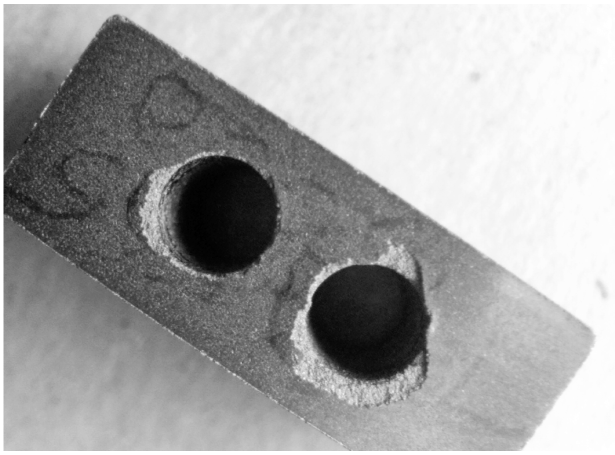




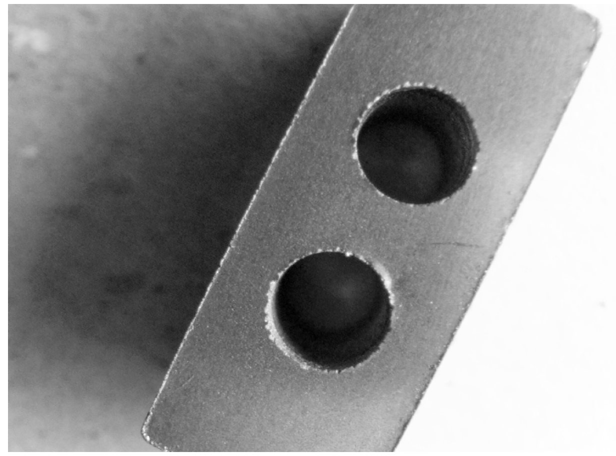
c) d)

Figure 8. Break-out at the Exit of Holes Drilled at a Cutting Speed of 3420 rpm and a Feed Rate of 0.08 mm/rev in:

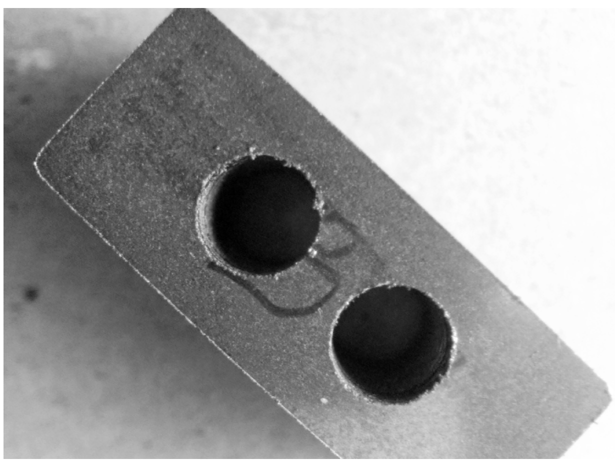
a) Material A (G.S. = 18 MPa).
b) Material B (G.S. = 52 MPa),
c) Material C (G.S. = 38 MPa),
d) Material D (G.S. = 90 MPa).



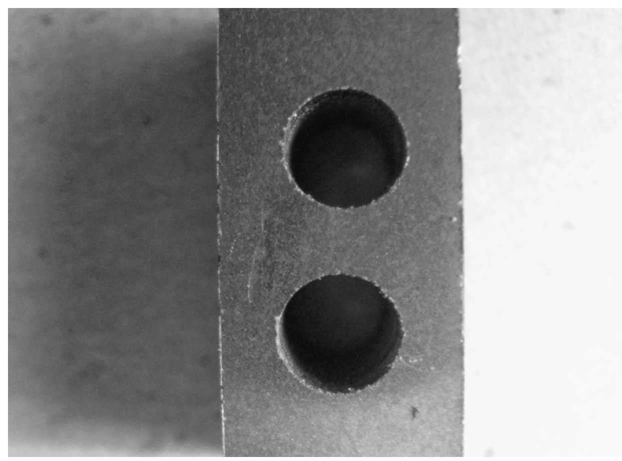
a)



b)



c)



d)

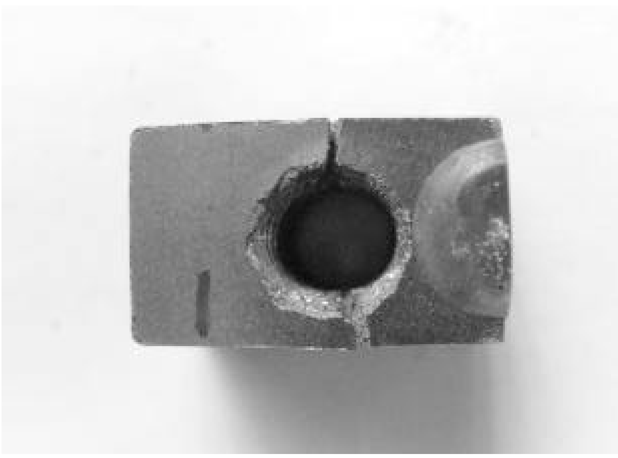
Figure 9. Break-out at the Exit of Holes Drilled at a Cutting Speed of 3420 rpm and a Feed Rate of 0.20 mm/rev in:

a) Material A (G.S. = 18 MPa),
b) Material B (G.S. = 52 MPa),
c) Material C (G.S. = 38 MPa),
d) Material D (G.S. = 90 MPa).

THREADING GREEN P/M MATERIALS

In many applications, drilling holes is a preliminary machining operation completed by a more complex and severe finishing step. Threading is probably the most common finishing step carried out after drilling. For this test, materials were first pierced with an "H" drill and threads 5/16"/18 were then manually made in the material.

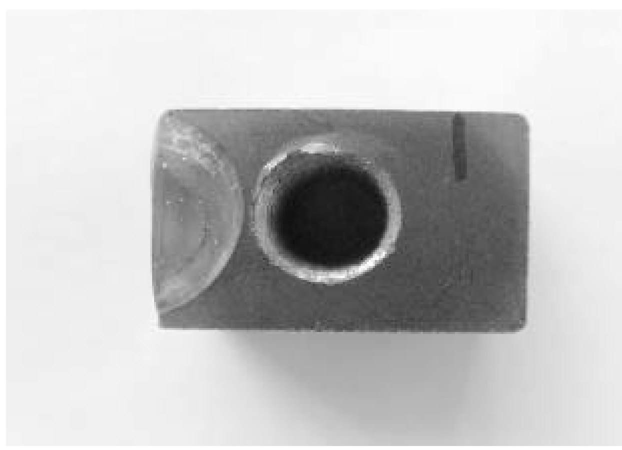
As seen in Figure 10a, material A which is based on a mix containing EBS is not suitable for threading. The radial stresses generated by the threading tool in the drilled hole exceeds the strength of the material and causes the rupture of the part. However, the green strength of the other materials was sufficient to support these stresses, Figures 10b, c and d. The surface of the specimens was slightly deformed during threading and burs may also be seen. These defects can probably be corrected by an adequate holding support or, as done in many cases, by deburring or tapering the entry of the hole. As shown in Figure 11, damage at the exit of the threading tap is minor and comparable to the one seen at the entry.



a)

b)

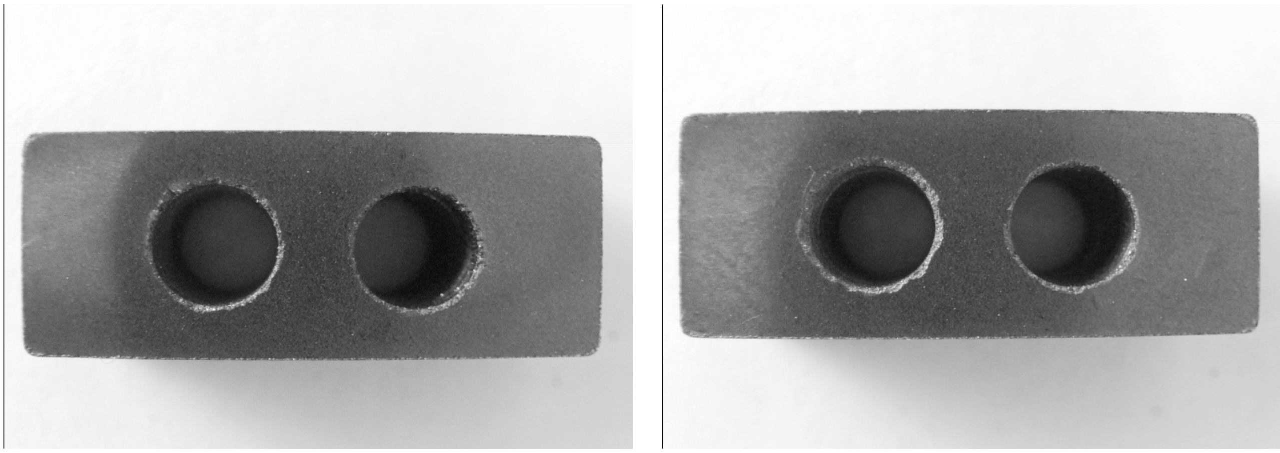
c)



d)

Figure 10. View of the Surface at the Entry Extremity of the Threads:

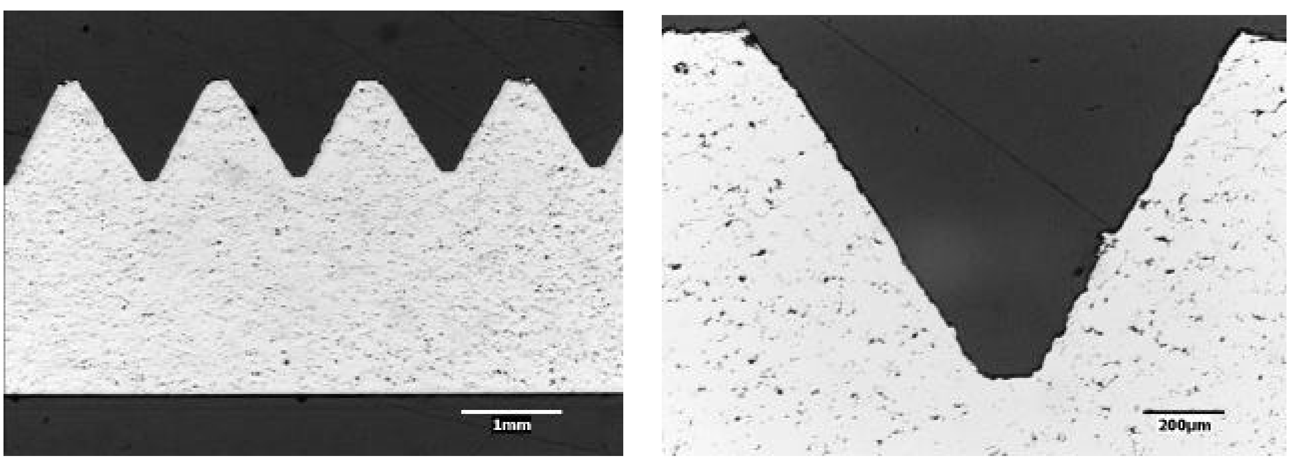
a) Material A (G.S. = 18 MPa),
b) Material B (G.S. = 52 MPa),
c) Material C (G.S. = 38 MPa),
d) Material D (G.S. = 90 MPa).



a) b)

Figure 11. Surface Views at a) the Entry and b) the Exit of the Threads Made in the As-Warm-Compacted Material.

The warm-pressed specimens with threads were then sintered as previously described. As seen in Figure 12a, the threads are very well shaped and exhibit a very regular profile. The close-up view of a thread, Figure 12b, reveals that the threading operation densifies the surface which results in increased mechanical strength and wear resistance. As shown in Figure 10, damage may occur at the entry and exit of the threaded holes which may be occasionally accompanied by cracks that form immediately under the surface of the parts. This indicates the stresses generated when cutting the first thread may exceed the green strength of the material. An increased green strength and an adequate fixture system that would maintain a slightly compressive stress on the component surface should prevent such problem. Finally, although the dimensional control of a threaded hole is critical, it is seen in Figure 13 that it can be accomplished. In this case, the threads made in the warm-compacted FN-0205 material match those of the fastener for which these were designed.



a) b)

Figure 12. a) View of the Threads in Warm-Compacted Material "B" after Sintering.
b) Detail of the Structure of a Thread Shown in a).

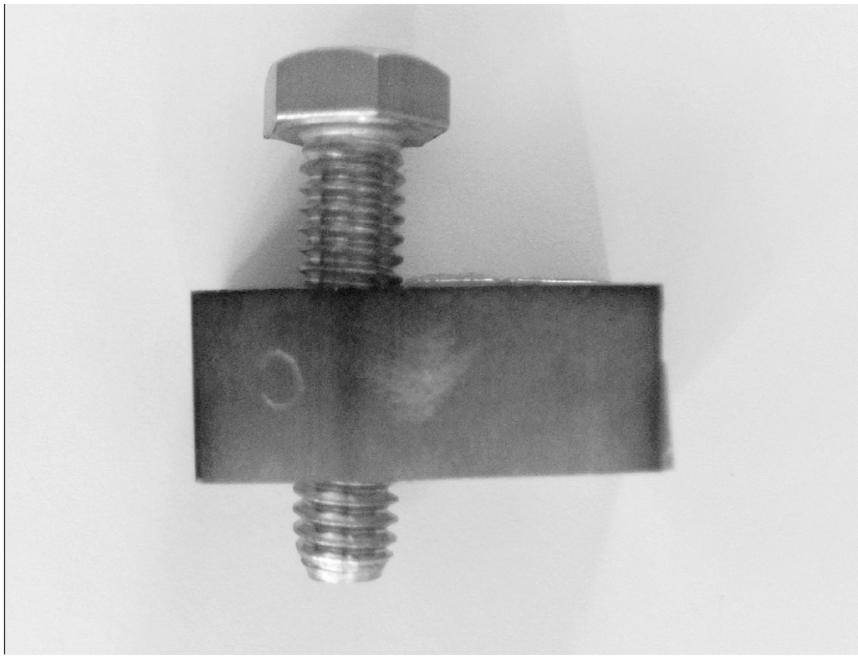


Figure 13. Example of Good Fitness between Sintered Threads Made by Green Machining and the Appropriate Fastener.

CONCLUSIONS

1.- Green machining reduces by a factor of 8 to 10 the stresses applied on the tool during drilling.

2.- In green parts, machining occurs via a combination of cutting and pulling out of particles.

3.- Green parts containing conventional lubricants and processed by single compaction cannot support green machining.

4.- New manufacturing processes such as warm compaction or the use of new polymeric lubricant systems allow the achievement of green strength high enough to permit green machining.

5.- The manufacture of threads is possible in high green strength materials; an appropriate fixturing system should prevent damage to the surface and/or formation of cracks.

REFERENCES

1.- D.F. Moore, Principles and Applications of Tribology, Pergamon Press, Oxford, 1975.

2.- M. Gagné and C. Labrecque, AFS Transactions, 1999, to be published.

3.- M. Gagné and J.P. Poirier, Hioga Hosai International Symposium on Recent Progress in Iron Powder Metallurgy, October 1996, Sendaï , Japan.

4.- M. Gagné, Advances in Powder Metallurgy, MPIF, Princeton, 1989.

5.- S. St-Laurent, M. Gagné and F. Chagnon, 1997 International Conference on Powder Metallurgy and Particulate Matrials, Chicago, June 1997.

6.- M. Gagné and J.A. Danaher, International Conference on Powder Metallurgy and Particulate Materials, Las Vegas, June 1998.

7.- F. Chagnon, S. St-Laurent, L. Tremblay and M. Gagné, SAE Technical Paper Series no. 1999-01-0337, SAE International Congress and Exhibition, Detroit, March 1999.

8.- L. Tremblay and Y. Thomas, 1999 International Conference on Powder Metallurgy and Particulate Materials, Vancouver, June 1999.