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An integrated approach to the characterization of powder metallurgy components performance during green machining

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Abstract

Green machining of powder metallurgy (P/M) components appears as an interesting procedure to solve the eternal problems associated with the poor machining behaviour of porous metallic samples. With the increasing usage of sinter-hardenable powders for high performance applications, green machining is an attractive method to lower production costs and compete against other shaping processes. Green machining is not a straightforward procedure. There is quite more to control in green machining than the cutting parameters. Several variables must be optimized to obtain adequate results in terms of surface finish, geometrical conformance and productivity. Other considerations such as density gradients in green compacts also influence the final outcome of this process. This study presents a new technique, based on cutting force measurements during green turning, to quickly and precisely characterize density gradients in powder metallurgy components. This new technique also allows the characterization of green machinability. Moreover, this study shows that timing sprockets can be produced by green machining of gear blanks. Timing sprockets produced by this process show a surface finish comparable to that of powder metallurgy components machined after sintering.

Keywords: Powder metallurgy; Green machining; Sinter-hardening; Green strength; Density gradients; Binder; Lubricant

1. Introduction

Powder metallurgy (P/M) is a near-net shape process that tends to eliminate the necessity of secondary shaping operations. However, features such as holes perpendicular to the pressing axis, undercuts and threads generally necessitate the use of machining operations [1]. Unfortunately, P/M components are difficult to machine due to their internal porosity, which induces microvibrations in the cutting tool and lowers the thermal conductivity of the material [2]. The machining of sinter-hardenable components is even more difficult since those samples exhibit hard microstructures (martensite + bainite). During the machining of such components, the temperature at the tool/chip interface increases significantly and the cutting tool life is considerably reduced.

A prospective avenue to improve the machining performances of P/M components is green machining. Green machining implies that the machining operations are done while the parts are in their "green state", before sintering. The advantages of this approach are impressive: tool wear becomes a negligible factor since the cutting forces applied on the tool are small and heat generation is minimal; the harder and/or tougher phases that are needed to obtain improved mechanical properties have not yet been formed since phase transformation only occurs at the end of the sintering operation. Thus, the productivity can be significantly increased because down time due to tool replacement is kept to a minimum. Nevertheless, important obstacles have to be addressed. The green strength of P/M components is generally low. For example, steel parts pressed to a green density of 6.8 g/cm^3 usually show green strength values of 12–17 MPa (∼1750–2500 psi). Therefore, the potential gains described above can easily be offset by the weak mechanical

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resistance of the green parts. The latter characteristic leads to poor surface finish, chipped or broken edges and sometimes broken parts. However, recent advancements in parts manufacturing as well as binder/lubricant technology open new leads in the development of green machining of P/M components. One method to make green machining possible is warm compaction [3–7]. This technique consists in pressing a pre-heated powder in a heated die at a temperature typically ranging from 90 to 150 °C. The green strength obtained from this approach is about two times larger than that provided by cold compaction [8]. Another option is the use of new binder/lubricant systems that have been developed to increase the green strength of P/M components without requiring heated compaction tooling. These polymeric binder/lubricant systems also offer the possibility of further strengthening the components by performing a curing treatment at approximately 175 °C following compaction [9–13]. The latter approach permits to increase the green strength of P/M components by a factor of 2–3. With such high green strength values, it is believed that green machining could be used to increase the productivity of the P/M process. Therefore, green machining could open up new fields of applications in powder metallurgy. Until now, P/M parts whit hard microstructures were often judged too difficult to be machined. However, with the development of improved binder/lubricant systems, it appears possible to perform machining in the green state and then sinter the parts to obtain the microstructure needed for the given mechanical properties.

It is well established that green density influences green strength [10–12]. A high green density, due to a high compacting stress, promotes increased particle movement and deformation, which are the bases for cold welding, mechanical interlocking and increased green strength [14]. However, due to non-uniform stress distribution during compaction, density gradients may be induced in green compacts. Die displacement during compaction as well as friction between particles and die wall are the main causes of pressure gradients that lead to the occurrence of density gradients. In double action pressing, the area with the lowest density is usually located near the mid-height of the component [2]. Thus, green strength gradients must also exist in a component with density gradients. Moreover, the cutting forces involved during machining are strongly influenced by the strength of the material [15]. If density gradients lead to green strength gradients, it will presumably lead to variations of the cutting forces applied on the tool during green machining. These cutting force gradients should vary in a similar way with the density gradients. In addition, machinability of green components, in terms of surface finish, is function of green strength. Since green strength varies within a green component, surface finish after green machining should vary accordingly.

The objective of this study was the development of a new technique to characterize density gradients in P/M components and its application to green machining evaluation. An investigation performed on gears in their green state was also conducted to simulate the machining of timing sprockets. This practical investigation was done to evaluate the effect of a curing treatment on the green machinability of high green strength compacts and to optimize the cutting parameters for surface finish.

2. Experimental procedures

2.1. Sample pressing

One series of samples was produced based on Quebec Metal Powders 4601 sinter-hardenable powder (Fe-1.8 wt% Ni, 0.55 wt% Mo and 0.2 wt% Mn) to which was added 2.0 wt% Cu and 0.6 wt% C. The latter premix follows the denomination FLC-4608 of MPIF [16]. Lubrication was done using 0.75 wt% of ethylenebisstearamide (EBS). Samples were pressed, using a 150-tonnes mechanical press (Gasbarre Products Inc.) into rings (50.8 mm o.d., 19.0 mm i.d. and 19.0 mm in height) to a green density of 6.80 g/cm^3. The compaction of these samples was done at a tool temperature of 53 °C, which is the typical temperature reached without external heating. The rings were used for the development of a new technique to characterize density gradients in P/M components. This new technique also allows the characterization of the green machinabilty based on the density gradients.

Other series of samples were prepared from a premix having the same chemistry described earlier and admixed either with 0.75 wt% EBS (reference material) or 0.65 wt% of a new binder/lubricant (FLOMET HGS^{TM}) specifically developed for high green strength. These two mixes of powders were pressed into gears (15 teeth, 50.8 mm o.d., 12.7 mm i.d. and 12.7 mm in height) at four different densities 6.60, 6.80, 7.00 and 7.20 g/cm^3. The compaction of these samples was done using a tool temperature of 65 °C, which is the typical temperature reached during pressing samples of this geometry without external heating. The gear-shaped samples were used for the simulation of the machining of timing sprockets in their green state. Finally, since the FLOMET HGS^{TM} system offers the possibility of further strengthening the components through a curing treatment, half of the samples produced were subjected to such a treatment, which consists in heating the parts in air at 175 °C for 1 h.

2.2. Sample holding for turning operations

A special fixture was developed to prevent the damage of the green P/M parts while held in the chuck of the lathe (Fig. 1). The samples had a hole in the middle and they were fixed to a wrought steel bar using a screw and a tight fitting bushing (Fig. 1). Thus, the steel bar was placed in the chuck of the lathe, preventing the jaws of the chuck from touching the P/M components. The turning was performed on a Mazak Nexus 100 CNC lathe.