GREEN MACHINING OF GELCAST CERAMIC MATERIALS

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ABSTRACT

Ceramic green bodies prepared by gelcasting were shown to be readily machinable using WC cutting tools. Samples of alumina and silicon nitride were examined. It was found that a gelcasting formulation which uses a high molecular weight cross-linking agent produces a green body having superior machining characteristics. Samples fabricated with a lower molecular weight cross-linker exhibited a poor machined surface finish due to chipping. Machining tests showed that using a 3.2 mm (0.125 in.) diameter cutting tool at a cutting speed of 162.5 cm/sec (64 ft./sec.) to machine a flat-bottomed groove 3.2 mm wide and 9.5 mm deep (0.125 x 0.375 in.) using three passes, feed rates ranging from 0.85 to 6.35 cm/sec (0.33 to 2.50 in./sec.) could be used without damaging the sample.

INTRODUCTION

Gelcasting is a ceramic forming process which offers distinct advantages as an alternative to the more conventional ceramic forming methods such as dry pressing, slip casting, and injection molding. The process was developed as a simple and economical method for producing complex-shaped advanced ceramic components. Gelcasting involves the dispersion of ceramic powders in a polymerizable aqueous monomer solution to form a fluid, castable slurry which is then gelled in the mold. The result is a very homogeneous cast body which shows a uniform chemical and density cross-section. Consequently, shrinkage during drying and firing is uniform (minimizing distortion) and material properties are constant throughout the body. A wide variety of ceramic materials have been prepared using the gelcasting process.

During the development of the gelcasting process for forming ceramic materials, one of the observations regarding the characteristics of gelcast ceramic materials was that the dried green bodies were exceptionally strong, even though they contained only 3 - 5 wt. % organic binder. This is believed to be due to the even distribution of the binder throughout the casting on the same scale as the powder particles. The high strength of the green body is of great advantage for handling of the parts before firing and for producing large castings. Experiments also indicated that the green parts could be machined. Although gelcasting was developed as a
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near-net-shape forming process, green machining of gelcast materials can be particularly useful for producing prototypes, for custom manufacturing, or for adding features to a cast part which would be too difficult or too costly to include in the mold. Some machining characteristics of gelcast ceramics were evaluated in the present study.

EXPERIMENTAL PROCEDURE

Gelcasting slurries of alumina (Reynolds RC-HP DBM) and silicon nitride (UBE SN E-10) were prepared by turbomilling the ceramic powders in an aqueous suspension. The alumina slurry contained 52 vol. % ceramic, while the silicon nitride slurry contained 46 vol. % powder. Two gelcasting chemical systems were used: 1) a 6-to-1 ratio of the monomer methacrylamide, MAM and the crosslinker methylene bisacrylamide, MBAM, a low molecular weight monomer and 2) a 3-to-1 ratio of MAM and polyethyleneglycol(1000)dimethacrylate, PEGDMA, a long-chain, higher molecular weight crosslinker. After milling, the slurries were vacuum deaired and cast into molds. The molds were placed in an oven at 60°C for 30 min. to gel the slurries. After cooling, the cast samples were removed from the molds and dried. Diametral compression tests were conducted to compare the green strengths of some of the samples. Machining of the cast billets was done using a lathe, a drill press, a surface grinder, and a computer-controlled, 3-axis milling machine.

RESULTS AND DISCUSSION

The green strengths of samples prepared using the two different gelcasting chemical systems were compared using diametral compression tests. The test results are summarized in Fig. 1. It can be seen from the figure, that the strength of gelcast materials is higher than that of samples prepared by other forming methods. This was reported in an earlier study. Also shown in the figure, is the lower strength of samples gelcast using MAM/PEG when compared to the samples gelcast with MAM/MBAM. The lower strength binder system was found to produce superior machined surfaces on samples which were turned on a lathe to cut threads in a rod-shaped billet. Samples with the high-strength MAM/MBAM binder system were prone to chipping during the machining process. Samples containing the MAM/PEG binder system were capable of retaining fine detail and a smooth surface finish. Examples of machined green ceramics with the MAM/PEG binder are shown in Fig. 2. The top sample in the figure is a silicon nitride component which was turned on a lathe and then fired to full density. The lower samples are gelcast alumina disks. Two of the disks were machined using a drill press and a surface grinder. The machined sample on the right was then sintered to full density.

Machining experiments were also conducted using a computer-controlled, 3-axis milling machine. This machine is pictured in Fig. 3. In addition to having its own drawing package, the machine can accept standard CAD files or scanned drawings for conversion to machining instructions. Shown on the monitor in the figure is the tool path for machining the upper half-surface of a button-head tensile rod sample.
Figure 1. Comparison of the tensile strength of ceramic green bodies measured by diametral compression testing. Note the lower strength of the alumina gelcast with MAM/PEG binder versus the alumina gelcast using MAM/MBAM.

Machining tests were conducted using the computer-controlled machine. A 3.2 mm (0.125 in.) diameter, flat-bottomed tool was used to cut slots in a green gelcast billet of alumina at a cutting speed of 162.5 cm/sec (64 ft./sec.). The tool was plunged to a depth of 3.2 mm (0.125 in.) and a 10-cm (4.0-in.) slot was cut at various speeds. Three passes were used on each slot to cut a total depth of 9.5 mm (0.375 in.). Feed rates ranging from 0.85 cm/sec (0.33 in./sec.) up to 6.35 cm/sec (2.5 in./sec.) were used to produce cleanly cut slots without causing any damage to the green ceramic.

Early machining experiments showed that tool steel wore rapidly when used for cutting gelcast ceramics. Machine tools having tungsten carbide (WC) cutting surfaces were used in the present study. An interesting observation of the machining characteristics of gelcast ceramics was that the tools removed the material from the billet in the form of turnings or shavings. Monitoring by health physics personnel showed that there was a very minimal amount of airborne dust generated; no protective breathing apparatus was required for workers.

Future plans for machining evaluation include: gelcasting chemistry modification, machining parameter determination, and tool wear assessment.

CONCLUSIONS

Ceramic green bodies prepared by gelcasting were shown to be readily machinable using WC cutting tools. Samples of alumina and silicon nitride were examined. It was found that a gelcasting formulation which uses a high molecular weight cross-linking agent produces a green body having superior machining characteristics.
Samples fabricated with a lower molecular weight cross-linker exhibited a poor machined surface finish due to chipping. Machining tests showed that using a 3.2 mm (0.125 in.) diameter cutting tool at a cutting speed of 162.5 cm/sec (64 ft./sec.) to machine a flat-bottomed groove 3.2 mm wide and 9.5 mm deep (0.125 x 0.375 in.) using three passes, feed rates ranging from 0.85 to 6.35 cm/sec (0.33 to 2.50 in./sec.) could be used without damaging the sample.

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Figure 3. Computer-controlled 3-axis milling machine used for conducting green machining studies of gelcast ceramic materials.

REFERENCES


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