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Cold Isostatic Pressing as a Method of Pre-forming Green Ceramic Ware

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Abstract

A method of manufacturing ceramic parts and ware, preferably from partially stabilized ultrafine zirconia, including pre-forming individual workpieces in paper or complex pressforms subjected to cold isostatic pressing; green machining; sintering and finishing is described. Examples of ceramic products made using the method are presented. © 1996 Elsevier Science Limited.

Introduction

Advanced ceramic products have now passed from demonstrating models into actual working parts and ware. Therefore, much interest is attracted to the service characteristics of ceramics as well as the cost aspects, rather than the standard material properties.

Reliable ceramics with high mechanical and service characteristics are produced from pure ultrafine powders. This implies low green density with large shrinkages and requires cold isostatic pressing (CIP) as a necessary processing route with green machining to remove distortions caused by the CIP shrinkage.

Pre-forming of powder compacts can be made using slip casting, injection moulding, pressing in steel pressforms, CIP in elastic moulds, etc.; the resulting compacts are then debonded and subjected to CIP at the chosen pressure. However, techniques based on organic binders and/or moulds are usually cost- and time-ineffective while dry compaction of ultrafine powders involves large distortions making precise pre-forming superfluous.

This paper summarizes experience of manufacturing ceramic products using pre-forming compacts in the single-use paper pressforms according to USSR Patent No. 1433804[1] with subsequent CIP and green machining of compacts.[2]

Experimental Procedures

The method consists:

(1) Calculating shrinkages and allowances starting from specified drawing sizes (S_i) and using predetermined densities: initial with tamping (ρ_o); green at pre-established CIP pressure (ρ_p); and sintered at pre-established conditions (ρ_s) as well as predetermined empirical machining and finishing allowances (A_M and A_F):

$$S_{Pi} = (S_i + A_{Fi})(\rho_s/\rho_p)^{1/3};$$
$$S_{oi} = (S_{Pi} + A_{Mi})(\rho_P/\rho_o)^{1/3}. \quad (1)$$

(2) Constructing paper pressforms according to the drawing with calculated sizes S_{oi}. The constructing material is a rigid packaging paper 0·13 mm in thickness and about 10 mg/cm^2 in density. The paper must be rigid enough to retain the given form, dense enough to be easily detached from the compact without any breaks, and soft enough to transmit the pressure uniformly.

(3) Stuffing the pressforms with prepared powder under vibrational densification or tamping; encapsulating them into rubber envelopes; evacuation and sealing.

(4) Pressing the sealed pressforms under pre-established pressure of working fluid; unpacking the compacts. This route of CIP can use compressor type or direct action hydrostats. The former possesses the advantage of large chamber volume, but usually has low productivity and is restricted by 0·2–0·3 GPa pressure. The latter, used in the present work, has much higher productivity and working pressures, but it is restricted by the chamber diameter. Standard laboratory presses made in our institute have working efforts about 1·4 MN and provide working pressures up to 1·5 GPa at a chamber diameter of 20 mm, 0·8 GPa at 45 mm, or 0·2 GPa at 90 mm.

(5) Green machining the compacts to the precalculated sizes S_{Pi} inside the allowance A_M in a specified tolerance. This route can include:

- Turning in a standard lathe under usual conditions. The main problem here is keeping the cutting tools sharp because a high-pressure compact is essentially abrasive, and standard carbide-tipped tools need frequent resharpening. Therefore, cutting inserts made from partially stabilized zirconia (PSZ) are recommended.
- Milling, drilling, and/or single-point-tool threading under the same conditions.

(6) Sintering and finishing the workpieces using A_F to the specified sizes S_i. Accuracy thus obtained increases due to decrease in workpiece size and can reach 0·01 mm or less before diamond finishing.

This method also allows production of parts with precise recesses or holes. They are made using ceramic inserts or cores, preferably from PSZ. Deep small-diameter holes can be obtained using specialized knowhow without drilling.

Only good quality mechanically stable PSZ (made in our laboratory) can be used as a material for the above tools and inserts as many times as necessary. Paper pressforms are single use, rubber (latex) envelopes can be used three to eight times.

Rejects for the developed product in a small batch process are usually less than 10%. Productivity for one laboratory equipment set (without any automation) is about 50 workpieces a shift depending on the product's complexity.

The above concerns mainly the shaping of bulk compacts. A problem of forming thin ceramic plates exists today also, especially in relation to manufacturing various-purpose cutting blades from PSZ. The main difficulty here consists in possible bending during CIP or sintering due to inhomogeneity across the plate's section. Slip or film casting usually does not provide a good quality ceramic suitable to obtain a sharp edge.

A method has been developed to form thin homogeneous flat plates with given thickness and profile using CIP in a special complex pressform with rigid flat surfaces. A controlling factor here is the friction between the powder and these surfaces.

Key Results

Most results were obtained using PSZ press-powder made in the laboratory from Ukrainian commercially available raw materials.

(1) A variety of simple parts and tool bodies of revolution have been developed and manufactured including: expanding heads (Fig. 1A); drawing dies and mandrels (Fig. 1B&C); cutting inserts (Fig. 1E); hip joint head (Fig. 1F) and others.

(2) A number of units consisting of ceramic parts of revolution have been manufactured as well including: roller bearing (Fig. 2A) and ball valve (Fig. 2B).

(3) Some parts with metric thread have been produced. using this method too (Fig. 3A). A thread is made in a standard screw-cutting lathe using standard tools. But since a standard lathe can cut only metric threads, one must choose such a pair of metric threads as to match calculated sintering shrinkage. The latter can be slightly controlled by adding a coarse fraction to the powder.

(4) Some complicated parts have been produced which can hardly be attained using any other shaping methods, e.g. slider bearings with internal recess (Fig.4) that cannot be either cast or hot pressed. Green turning the recess is significantly simpler than final diamond grinding.

(5) A large quantity of ceramic (PSZ) plates with various thicknesses and profiles has been produced including: ceramic knives (green thickness

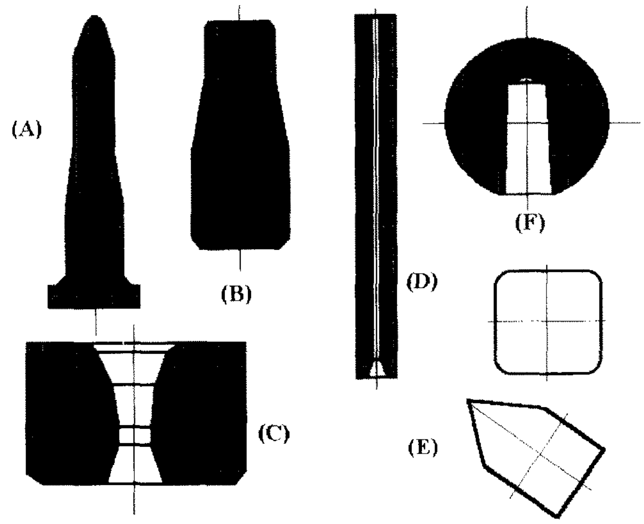

Fig. 1. Examples of simple parts and ware manufactured using CIP and green machining.

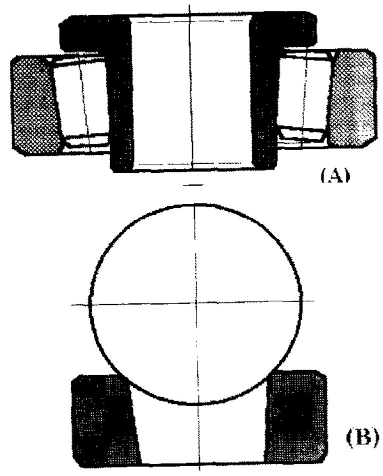

Fig. 2. Examples of ceramic units.

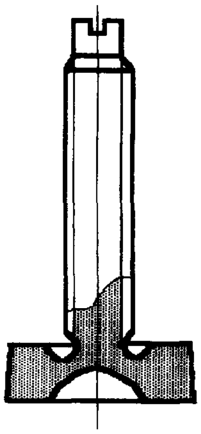

Fig. 3. Example of the ceramic part (adjusting stop screw) with metric thread made by screw cutting after CIP.

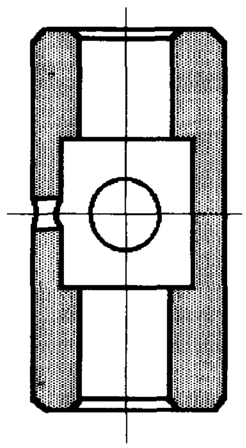

Fig. 4. Ceramic slider bearing with internal recess: an example of a shape that can most easily be made using the method described.

T = 4 mm); scalpels and mill compartment lining plates (T = 3 mm); various purpose blades (T = 1 mm or less). The profile of such workpieces can be easily calibrated by green machining. Productivity in this case can reach 50 or more workpieces a shift depending on size.

Conclusions

One of the major results obtained is that ceramic parts and ware should not be produced by diamond cutting of sintered blocks after CIP due to obvious degradation in properties. It is explained by nonuniform density distribution across a green body after CIP in relation to strong pressure dependence of the properties. Therefore, green parts/ware must be shaped under this method individually and subjected to only minimum finishing if needed.

This method of shaping complete with press-powder preparation procedures and further sintering and finishing is considered as a nucleus of future profitable industrial process and technology.

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