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ISOSTATIC PRESSING OF CERAMIC ARTICLES IN THERMOPLASTIC MOLDS

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The technology for construction ceramics based on cold isostatic pressing makes it possible to obtain articles with high values of the required properties. Nonetheless, the use of isostatic pressing is often limited by difficulties related with obtaining shaped articles with fine elements and large length-to-transverse section ratio. The method proposed for isostatic pressing of powders in thermoplastic molds aids in solving this problem. The particularities, advantages, and drawbacks of such molds are examined.

Key words**:** cold isostatic pressing, thermoplastic materials, 3D-printing, ceramic powders, construction ceramic.

A well-known method of obtaining high-quality blanks of ceramic articles from powdered materials is the technology of cold isostatic pressing (CIP) in molds (enclosures) made of elastic materials. CIP is used to obtain large- and small-size articles of complex shape with uniform density and ideal material microstructure [1 – 3].

However, often, the compacts disintegrate in CIP of shaped articles with fine shape elements as well as in pressing powders with low interparticle bonding strength. This is because the elastic mold rebounds to its initial dimensions once the pressing pressure is removed. The rebounding mold carries the pressed material with it, stretching and destroying the compact.

The use of thin-walled shells incapable of destroying the pressed article solves this problem in part. Since thin shells hold their shape poorly, rigid supporting elements are introduced into the design of the mold. For this, the elastic shells are often placed inside perforated or porous sleeves with the corresponding shape [4]. Such molds have two drawbacks: they disrupt the isostatics of the pressing process and the resulting density of the compacted material is nonuniform. Moreover, because the elastic moduli of the elastic and rigid elements of the mold have different values the geometry of the articles becomes distorted upon pressing [5, 6]. In consequence, additional machining becomes necessary. Thus, though it surpasses other methods of powder technology in terms of the quality of the microstructure of the molded blanks CIP loses for fabrication of articles with complex shapes.

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One solution of the problem of fabricating articles with complex shapes by means of CIP could be to use molds made of materials possessing the property of thermoplasticity and to conduct the pressing operation at heightened temperature. Such molds hold their shape well during the powder filling process conducted at room temperature, and upon heating they transition into a plastic state, making the pressing process isostatic. The initial dimensions of the molds are not restored after pressing, so that the pressed blanks remain intact. In addition, the shape of the compacts can be as close as possible to the shape of the finished articles. This makes it possible to eliminate or significantly reduce the volume of additional machining.

We shall examine the particularities, advantages, and drawbacks of the technology of isostatic pressing of ceramic powders in thermoplastic molds.

FABRICATION OF MOLDS

We propose using low-melting thermoplastics for the molds: wax, paraffin or polymers used for rapid prototyping. These materials eliminate the elastic rebound to the initial dimensions of the molds when the pressing pressure is removed.

The molds can be fabricated by casting thermoplastic materials, stamping, and machining or by 3D-printing. The mold designs contain openings for pouring powder. The molds are unit-cast or composite. The individual parts are joined and the molds sealed by melting or coating with the thermoplastic material from which they are made.

Polymer 3D-printing technology can be used to fabricate the molds. The current CAD-CAM systems for 3D-printing

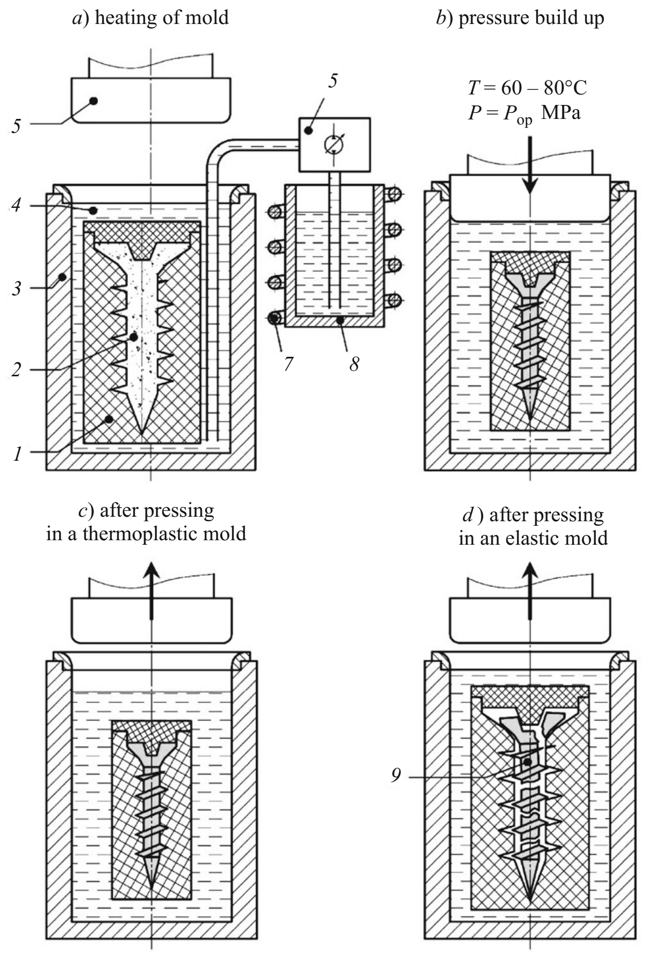

Fig. 1. CIP scheme: *1*) thermoplastic mold; *2*) ceramic powder; *3*) high-pressure container; *4*) working liquid; *5*) pusher; *6*) pump; *7*) heating element; *8*) tank with working liquid; *9*) example of a broken compact in the case of pressing in an elastic shell.

make it possible to rapidly create inexpensive parts with high dimensional accuracy. In addition, it is possible to fabricate the molds themselves as well as models of the compacts that will serve as a base for subsequent casting or stamping of molds from materials with a lower melting temperature.

Suitable materials for 3D-printing of thermoplastic molds are modeling wax and polymers used for fast prototyping. The commonly used materials for 3D-printing are ABS (copolymer acrylonitrile-styrene-acrylate) and PLA (polyester based on lactic acid) plastics. The softening temperature of ABS plastic is about 100°C, so that it can be used to fabricate the mold models. The softening and melting temperatures of PLA plastic are 60 and 100°C, respectively. This makes it possible to use this plastic for the models and the molds themselves. The modeling wax used in jewelry production as well as polymers with low — down to 50°C — softening temperature are used for the molds.

The high accuracy of molds obtained by 3D-printing makes it possible to press blanks previously fabricated only by means of the technologies used for molding plasticized powder materials.

CIP IN THERMOPLASTIC MOLDS

Prior to pressing or directly during the pressing process the filled mold must be heated to the temperature at which the mold material transitions into the plastic state. Pressing is accomplished in a high-pressure container on an isostatic pressing setup equipped with heater for heating the molds and a working liquid (Fig. 1). After building up the pressure and holding for a prescribed period of time the pressure in the container is lowered and the mold is extracted.

In fabricating thermoplastic molds, materials with low melting temperature (50 – 150°C) make it possible to use ordinary equipment for cold isostatic processing [7].

For convenient extraction of the compact from the mold the latter must be heated or melted. Melting a mold in a hot air stream makes it possible to gradually remove the thermoplastic material from the surface of the compact to the extent that the material melts. This reduces the load of the melting material on the fine shape elements of the articles and damage to the articles is prevented. The melted material is subsequently recycled for fabricating new molds.

DRAWBACKS OF THERMOPLASTIC MOLDS AND METHODS FOR REMOVING THE THERMOPLASTIC

The main drawback of the solution studied here is that molds made from such materials are used only once because of the irreversible reduction of the dimensions during pressing. However, this drawback is compensated by the possibility of reusing the mold material and the ease of fabricating molds.

The drawbacks also include the fact that during pressing the mold material, which is in a plastic state, can penetrate into the surface of a porous compact. This process is all the more intense the greater the hardness and porosity of the powder material and the lower the viscosity of the mold material in the plastic state. In consequence, the structure of the pressed material breaks down and extraction of the compact from the mold becomes problematic.

When an article is removed from the mold by melting the mold, melt permeates into the pressed material. The loosening of the material as a result of permeation results in the formation of a porous defective layer on the surface of the article; this layer remains after sintering. The need to remove this layer complicates the fabrication process and makes it impossible to render the fine shape elements of the article.

This problem can be solved by covering the surface of the cavity of the mold by a thin layer of elastic insulation material that protects the powder from the permeation of the melted mold material during the pressing process and extraction of the blank [8]. The thin protective layer does not tear

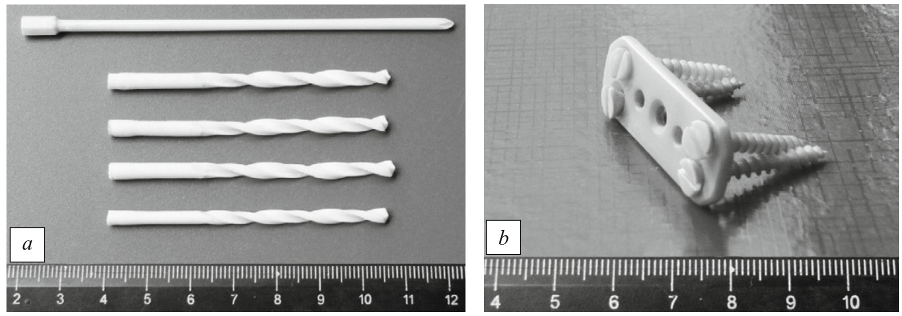

Fig. 2. Articles obtained by pressing in thermoplastic molds: *a*) ceramic drills and screwdriver blade; *b*) spinal implant made from zirconium dioxide.

because during isostatic pressing all dimensions of the mold decrease proportionally. The presence of a protective shell, because of its small thickness, does not destroy the isostatics of the pressing process and does not distort the shape of the compact.

In this case the mold essentially consists of two shells — a thick outer shell made of the thermoplastic material and a thin inner elastic shell. As powder is poured into the mold before heating, the outer shell acts as a rigid element, providing support and shaping the inner shell. During pressing in a heated state the material of the outer shell transitions into the plastic state and serves as a pressure transmitting medium. This ensures uniform compression of the powder and the production of high-quality articles with a complex shape and a homogeneous and equidense structure of the material.

For some thermoplastic materials very small shrinkage is still observed upon cooling. In this case the reduction of the dimensions and simultaneous reduction of the plasticity of the molds lead to breakage of the fine shape elements and even to complete destruction of the compacts. This is especially characteristic for compacts made from powder with low interparticle bonding strength. For this reason, to fabricate such articles the compacts must be extracted immediately after pressing without allowing the mold to cool significantly.

When a mold is fabricated defects in the form of cavities and cracks are formed because the thermoplastic material congeals nonuniformly. As a result of the appearance of such defects and nonuniform heating of the mold during pressing, the compacts become curved and protrusions form on the surface of the compacts. The insufficient thickness of the walls of the mold at the locations of sharp changes in the shape of the cross section destroys the integrity of the mold and allows the working liquid to permeate into the powder.

EXAMPLES OF MOLD APPLICATIONS

The efficacy of thermoplastic molds, including molds made by 3D-printing, was checked for the fabrication of ceramic articles with fine elements: surgical implants (plates and wood screws), drills, and screw-driver blades (Fig. 2). The articles were fabricated from granulated oxide-ceramic powders based on partially stabilized zirconium dioxide. Pressing in molds made from modeling wax was conducted at CIP pressure 0.3 GPa and temperature 50 – 60°C.

CONCLUSIONS

The use of thermoplastic molds in isostatic pressing technology is one method of solving the problems of fabricating shaped articles with fine shape elements and elongated articles with variable cross section. The use of low-melting materials with a low (to 150°C) transition temperature into the plastic state for molds makes it possible to use them in the CIP technology and equipment. Thermoplastic molds have two advantages: simplicity and low labor-intensiveness of manufacturing. In addition, the use of modern 3D-printing technologies for manufacturing molds affords the following:

– higher productivity and lower cost of manufacturing of thermoplastic molds;

– higher dimensional accuracy of molds;

– use of isostatic pressing for fast prototyping of ceramic articles with complex shapes.

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