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D. E. TOMKINS

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PROCESS FOR THE MANUFACTURE OF CERAMIC OBJECTS

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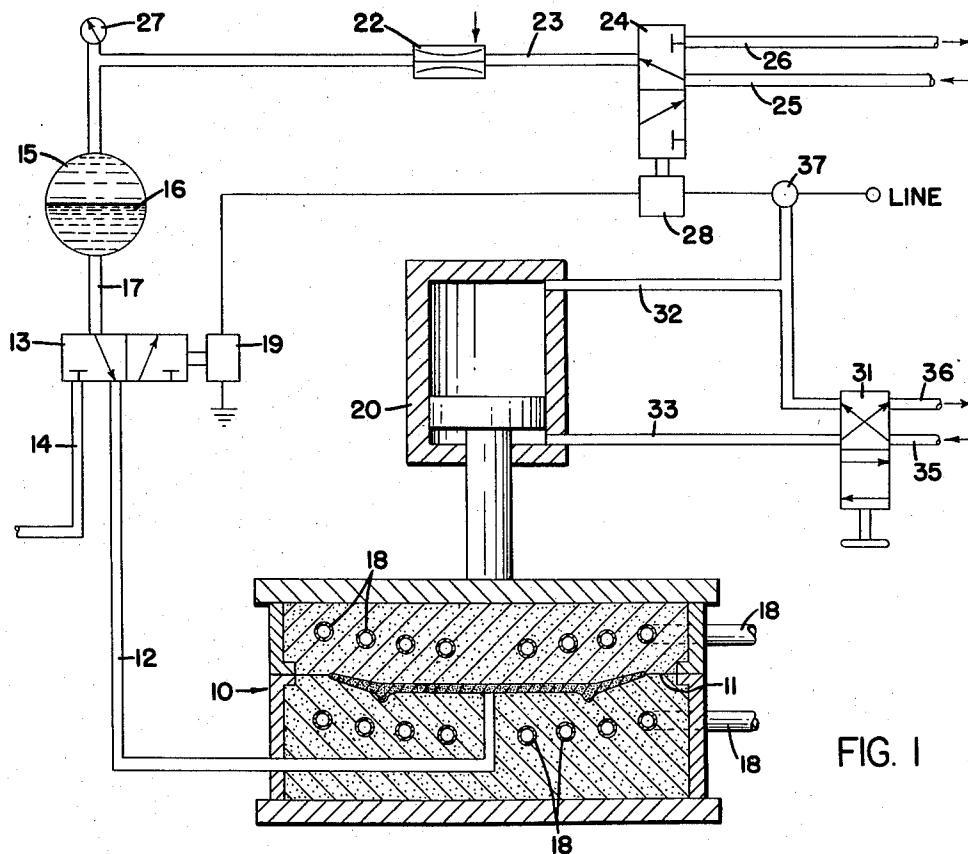


FIG. 1

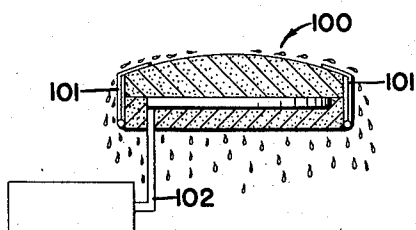


FIG. 2

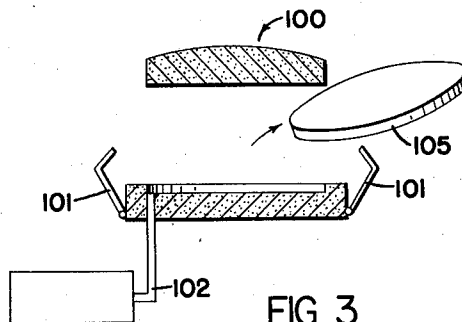


FIG. 3

INVENTOR
DAVID E. TOMKINS

BY *Ely, Foye & Hamilton*

ATTORNEYS

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PROCESS FOR THE MANUFACTURE OF CERAMIC OBJECTS

David E. Tomkins, New Castle, Pa., assignor to Shenango China, Inc., New Castle, Pa., a corporation of Pennsylvania

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This invention relates to the manufacture of ceramic objects made wholly or partly from clay or other fine-grained substances.

The several processes for the forming of ceramic shapes or objects may be classified according to the nature or state of the clay or fine-grained substance which is used. According to such a classification, there are three basic types of processes: (1) slip processes; (2) plastic processes; and (3) dry-press processes. The dry-press processes are foreign to the subject matter of the present invention and not further discussed herein.

In the slip processes a mixture of water and clay or clays such as kaolin and/or ball clay, or clay-like substances such as very finely ground deflocculated alumina, with or without additional ingredients such as feldspar or flint are brought to a fluid or semi-fluid state characterized in the art by the name "slip," the slip being then introduced into a porous mold, which, by withdrawing water from the slip, produces green ware of the desired shape.

Such slip processes include the method of slush casting (drain casting) used in production of hollow shapes which cannot be turned, such as ovoid bowls and jars. Slip processes also include the methods known in the art as gravity solid casting and pressure solid casting. An example of gravity solid casting is found in Wadman U.S. Patent No. 2,288,661, issued July 7, 1942. Examples of pressure solid casting are found in Eckstein U.S. Patent 1,163,328, issued December 7, 1915; Montgomery U.S. Patent 1,864,365, issued June 21, 1932; Bower U.S. Patent 2,273,016, issued February 17, 1942, and Blackburn U.S. Patent 2,669,762, issued February 23, 1954.

Pressure solid casting is distinguished from gravity solid casting by accelerated removal of water into the water-absorptive mold walls. Pressure feeding of the slip results in such hastening of water absorption, as set forth explicitly in Montgomery's patent specification. The Bower disclosure relates to a method of feeding slip to the mold at a rate which varies within each feeding cycle. The Blackburn patent is directed to a quick mold release technique applicable both to conventional pressure solid casting and gravity solid casting methods.

Common to the slip processes of the prior art, examples of which are found in the above patents, is the removal of the water of suspension by the absorptive action of a water-permeable mold, thus converting the matter fed to the mold from a fluid or semi-fluid slip to a leather-hard agglomerate mass capable of at least approximately sustaining its shape. In some instances, as outlined above, the removal of the water of suspension may be aided or accelerated by pressure feeding of the slip. According to Montgomery, pressure-fed slip is reduced to a leather-hard state ready for removal from the mold within several minutes. According to Blackburn, irrespective of the period of time required to form the solid leather-hard object within the mold (whether by gravity or pressure casting), additional time for natural

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shrinkage must be allowed in order to separate the shaped article from the mold without damage in the absence of the quick release technique to which his patent is directed. In the practice of all the above patents, the green formed article remains subject to typical substantial shrinkage during drying prior to firing, such shrinkage of green ware or shapes being a well-known and characteristic phenomenon in the art.

In the solid slip casting processes of the prior art, referred to above, water of suspension is filtered from the injected slip by the porous mold walls. As a layer of matter from which the water of suspension has been removed starts to build up, the water of suspension of the newly incoming slip must be forced and absorbed therethrough in order to continue the conventional dewatering operation. The plastic agglomeration of particles within the mold builds backwardly toward the slip feed passage or passages until the mold cavity is entirely filled, such procedure requiring several minutes in the case of pressure casting and considerably more time in gravity casting. The plastic mass apparently comprises a continuous water phase which surrounds each particle with a water film and through which, at intermediate stages, water of suspension from freshly arrived slip may continue to flow.

The plastic processes of the prior art include a number of types of operations on a mixture of water and clay or clay-like materials with or without additional ingredients which are brought into a condition known in the art as the plastic state. The plastic mass may then be jigged, hand-molded or pressed between water-absorbent molds. Shapes may be successfully formed from relatively stiff plastic masses by extrusion. Injection molding has been used, a finely ground non-plastic (and non-liquid), mixed with about fifteen percent of thermosetting and thermoplastic resin, being forced from a heated chamber into a cooled mold, the chilled piece being then heat-treated to remove the organic matter.

Considerable work has been done in connection with those plastic processes which employ porous molds or molds having porous faces designed to absorb water from the plastic mass while confining the solid components of the mass within the mold cavity. An early example is found in Westman Patent 1,864,365. Another example of a type of die structure which has recently been commercially employed is of the general type illustrated in Figure 7 of Jordan Patent 2,638,654. Certain detailed reference to these patents will be made in order that the significance of the present invention may be most clearly understood.

In Westman's disclosure, it is to be noted that the dies or "pistons" comprising the "plungers" 4 are forced together to the full extent necessary to remove water from the plastic mass. Thus, the thickness of the formed mass is determined by at least three factors: (1) volume of plastic mass prior to forming; (2) water content of plastic mass prior to forming; (3) size or sizes and shapes of solid particles in plastic mass. These three factors, and possibly other factors, are variable to a degree which precludes accurate control of final thickness. Only by great coincidence will a desired thickness be arrived at in the formed piece, and this desired thickness cannot be maintained from piece to piece. On the other hand, imagine that a stop is provided in Westman to limit travel of the plungers so as to standardize thickness by stopping plunger travel at a point short of that travel which accomplishes complete compression (which amount of travel for complete compression varies from operation to operation as pointed out above). If a stop is provided in Westman, certain portions of the pressed mass are more completely de-watered than others at the conclusion of the pressing operation. Also, the degree of

de-watering varies from operation to operation. De-watering is accompanied by volume shrinkage and uneven watering and uneven pressure of forming cause warpage, strain and cracks which may appear before or after firing. The die structure shown in Figure 7 of the Jordan patent illustrates a water-absorbent die structure in which compressing travel of the dies is positively limited. While it is feasible for forming smaller pieces of ware it has the disadvantages outlined above.

The type of operation illustrated in Jordan's Figure 7 is dissimilar to Westman in significant respects other than the provision of travel stop. Excess plastic mass is relieved in gutters or channels shown in diamond-shaped cross section in Jordan's Figure 7. This holds the range of de-watering variation throughout the mass from operation to operation within reasonable limits while allowing close thickness control. (Westman, if provided with a travel stop, would vary more widely in degree of de-watering from piece to piece because of the absence of such relief.) At the same time, the relief provided in the Jordan operation limits the molding pressure which may be achieved and occasions some unevenness of pressures insofar as portions of the cavity (the rim in Jordan's Figure 7) are relieved from pressure to a greater extent than other portions (center portion of cavity in Jordan's Figure 7). The type of operation illustrated in Jordan's Figure 7 is also dissimilar to Westman in that a limited amount of moisture is deliberately blown back to the die faces to effect ware release. It is to be noted that the Westman patent (see particularly page 2, column 1, lines 19-24) teaches that water in contact with the mass will work against the de-watering sought to be achieved, particularly at higher molding pressures. However, the blow-back of a relatively small amount of moisture for ware releasing purposes as in Jordan has been found to be not too objectionable. Blow-back of a small amount of moisture for ware-releasing purposes is also shown by Blackburn in connection with solid casting.

The present invention relates to a slip process and embodies the discovery that, entirely contrary to the teachings of Westman in regard to moisture contact, the soil mechanics of slips are such that surface tension or particle-water interface effects may be overcome and shrinkage water may actually be expressed from between the clay particles or other fine particles comprised in the slip within a porous mold even when employing as the compressing medium a liquid or suspension (which may most simply be additional slip succeeding that supplied through an input line to the mold cavity) provided that the compressive medium is applied to the slip within the porous mold at investment pressures greatly exceeding those employed in the most closely related prior art dealing with slip processes. Such removal of shrinkage water is supplemental to removal of water of suspension. Although water is the essential compressing medium, the slip particles within the mold cavity actually impinge together under the high imposed fluid pressure, and upon release of pressure following formation of the article and previous to its removal from the mold there is no substantial reversal of the de-watering action despite the direct contact of the de-watered "shrunk" article with the fluid which imposed the pressure. Thus, in a sense, the overcoming of surface tension or particle-water interface effects so as to eliminate shrinkage water in addition to water of suspension may be said to be irreversible or, more accurately, non-reversing in the practice of the invention.

The invention also embodies the discovery that such non-reversibility, as referred to just above, obtains even when substantially the entire surface area of an article which is deprived of substantially all shrinkage water as well as water of suspension is subjected to direct water contact, as for releasing purposes.

As used herein the term "shrinkage water" is used to designate that water the removal of which is accompanied by shrinkage of the clay body from which such water is

removed (which body has previously been rendered incapable of fluid flow by removal of "water of suspension").

The invention embodies the further discovery that, at elevated pressures, de-watering may continue to occur under a fluid-imposed pressure despite the progressively closer packing of the clay or clay-like particles. It is not clear whether expressing of the shrinkage water is delayed until the mold is almost filled with a mass from which water of suspension has been removed, at which time such expressing takes place more or less simultaneously throughout the mass, or whether de-watering continues through the interstitial spaces remaining between the closely packed particles of outer laminae after removal of all or nearly all shrinkage water in such laminae. In any event, the residuum of matter remaining within the mold constitutes a substantially pre-shrunk article, thus avoiding all the problems and disadvantages of the heretofore characteristic shrinkage of newly-formed green ceramic shapes and objects, while at the same time close thickness control is achieved. Pre-shrunk articles formed according to the present invention contain very little, if any, shrinkage water, the process removing most of the film of water surrounding each particle by overcoming the surface tensions involved so that substantially all remaining water fills voids between touching particles. Not only is drying shrinkage eliminated, but drying time is also greatly reduced. Accordingly, the invention avoids all the problems of non-uniformity of results or of warping, uneven drying, unmatched shrinkage of thick and thin sections, and irregular shapes, which problems have heretofore plagued the art.

It may be added that in the porous-die plastic processes such as Westman and Jordan, air bubbles within the plastic mass, although collapsed incident to the compressing and de-watering operation, nevertheless leave their trace in the form of shallow blebs or faults. In my invention, de-watering is substantially uniform throughout a section of varying thickness because throughout the de-watering operation there is no significant variation in pressure between thick and thin portions of the section. Also, the constant supply of incoming slip under pressure completely eliminates all trace of air bubbles in the molded article—it de-airs in addition to de-watering.

The invention is also superior to the several plastic molding processes of the prior art because the invention, unlike such plastic molding processes, involves a high degree of preferred orientation of the clay particles of the molded piece for greater strength, smoothness, and firing shrinkage uniformity and control.

The actual molding operation to which the invention relates compares in speed with the pressing operation in plastic processes such as those to which Westman and Jordan relate. Furthermore, this comparison of speed of operation is entirely apart from the saving in time and overhead effected by the invention by its elimination of any necessity of blunging and otherwise preparing a plastic mass (Westman blunges for eight hours in his example). Ware pieces may be formed according to the present invention within several seconds following initiation of pressure investment of the slip. In comparison with prior slip casting methods, formation of the piece in the present invention is much more rapid (Montgomery required several minutes).

The invention is applicable to the production of those shapes usually produced by jiggering and solid casting. It eliminates the necessity of filter presses, pug mills, elaborate clay-delivery equipment and large mold inventory in the forming of such shapes. It eliminates the necessity of skilled batterouts and jiggermen or the provision of complex automatic jiggering equipment. Drying equipment may be simplified. Small production runs of miscellaneous sizes and shapes may be made economically. Scrap return is virtually eliminated.

The invention is adaptable to automatic and continuous

production and to the production of pieces having walls of varying thickness or any arbitrary shape. It produces a leather-hard piece with substantially no drying shrinkage. The process removes most of the film of water surrounding each clay particle known as "shrinkage water," substantially all the remaining water filling voids between touching clay particles. As explained below, the invention also makes possible several novel means of decorating mass produced ware.

It is to be understood that the invention would be applicable to the forming of ceramic pieces by use of suitable vehicles or suspending agents other than water, and accordingly the word "water" throughout the specification and claims is to be regarded as embracing both water itself and other equivalent vehicles or suspending agents.

The objects and advantages of the invention as described above will become more apparent from the following specification of the invention. The means which have actually been employed to practice the invention are illustrated schematically in the accompanying drawings. While additional work may be expected to yield refinements in the invention, the herein disclosed specific embodiment describes the most desirable form of the invention of which I am presently aware and will enable those skilled in the art to successfully duplicate my practice of the invention.

Figure 1 illustrates an embodiment of the invention which has been experimentally tested. Figures 2 and 3 are highly schematic illustrations of the sequence of operations in the practice of the invention.

In the apparatus illustrated in Figure 1, a porous die or mold 10 having a parting line 11 is provided. The mold 10 may be a plaster mold of the type heretofore used in plastic pressing operations being suitably supported by metal cladding and having inset fiberglass tubing 18 communicating with the outside of the mold. The permeable walls of the fiberglass tubing pass water absorbed by the mold 10, allowing such water to drain from the mold assembly. An air pressure supply means (not shown) may also communicate with the tubing 18. A supply line 12, preferably a metal line, communicates with the mold interior and leads from the slip valve 13. A slip supply line 14 supplying slip at sufficient pressure to cause flow communicates with the valve 13. A tank 15 is provided having a central flexible diaphragm 16, the lower portion of the tank 15 communicating with the valve 13 through a line 17. The valve 13 is actuated by a solenoid 19 which, when energized, shifts the valve 13 to the illustrated position. The upper portion of the tank 15 communicates through a line 23 with an oil valve 24 to which are ported a line 25 leading from a source of oil pressure and a dump line 26 leading to an oil reservoir. The oil pressure may be supplied by conventional pump means having a suitable adjustable relief valve enabling any desired pressure over a wide range to be selected and maintained, as will be obvious to those familiar with hydraulic control systems. An adjustable flow control valve 22 is inserted in the line 23 to which may also be attached a suitable pressure gauge 27. The valve 24 is actuated by a solenoid 28 which, when energized, shifts the valve 24 to the illustrated position.

A hand-operated press control valve 31 is provided. Ported to this valve are the lines 32 and 33 leading to opposite ends of a hydraulic cylinder 20, which is adapted to actuate the upper die of the mold 10 and to hold the die in open or closed position. Also ported to the control valve 31 are line 35 leading from a source of hydraulic fluid pressure and line 36 leading to a hydraulic fluid reservoir. The oil supplied to the tank 15 and the hydraulic fluid supplied to the cylinder 20 may or may not be identical; actual experimental practice of the invention happens to have been performed with different liquids and independent pressure supply systems.

A pressure switch 37 is ported to the line 32 and is adapted to be closed when pressure in this line rises above

a predetermined value and opened when pressure falls below this value. The solenoids 19 and 28 are in series with this pressure switch.

When the handle 31 is in the position illustrated, hydraulic fluid is admitted to the hydraulic cylinder through the line 32, the top die of the mold 11 being lowered into closed position as shown in Figure 1. When the top die can no longer move, pressure in the line 32 increases and causes the pressure switch 37 to energize the solenoids 28 and 19. The valves 13 and 24 thereupon assume the positions illustrated in Figure 1. Oil at a molding pressure of 600 p.s.i. or over is admitted to the top half of the tank 15, the rate of flow being controlled by the valve 22. Slip in the bottom half of the tank 15 is forced through the line 12 and into the mold at the same pressure. Water filtered from the slip within the mold is forced through the mold and allowed to drain away through the tubes 18. Slip within the mold 10 is transformed into a pre-shrunk leather-hard shaped mass from which most or all of the shrinkage water has been removed, the clay or clay-like particles of this mass being oriented along their directions of flow into final position or generally along directions parallel to the interior mold surfaces. Apparently such particle orientation, by reducing the volume of voids between particles, minimizes the volume of water remaining within the mass following removal of shrinkage water. Minimizing of such volume further reduces the residual moisture within the formed article, thus further shortening drying time. Relatively little water escapes from the slip within the line 12 because of the confining effect of the metal walls of this line.

After a short time interval, not usually exceeding several seconds, compressed air may be momentarily admitted into the lines 18 to blow moisture back to the die faces to enable ready release of the formed piece of ware, and the valve 31 may be reversed, causing the upper mold die to be raised. With the corresponding pressure drop in the line 32, the solenoids 19 and 28 are de-energized, causing the valves 13 and 24 to reverse and allowing a fresh supply of slip from the line 14 to be admitted in the tank 15. The formed piece is removed from the mold 10, and the apparatus is ready for a succeeding molding operation.

In one experiment, six-inch diameter cereal bowls were produced as follows. A slip was provided consisting of the following ingredients, all of solid ingredients having been passed through a 150 mesh screen:

	Percent by weight
Pennsylvania flint	28.5
Potash feldspar	13.9
Marble	1.5
C & C Ball clay	7.5
E.P.K. kaolin	8.2
1300 English china	15.4
Water	25.0
	100.0

This slip was prepared in the conventional manner and was supplied from the slip feed line at a pressure of 70 p.s.i. During molding, oil pressure of 750 p.s.i. was applied to the oil-slip tank. Slip was fed into the mold under pressure for 15 seconds. At the end of this time, compressed air at 80 p.s.i. was ported to the fiberglass tubing, and the mold was opened and a piece of ware, of leather-hard consistency, was removed from the mold. The pieces were thereupon dried and were fired for 60 hours at 2240° F. in a sanded bung. No apparent warping occurred during firing. The surfaces of the fired pieces were examined and found to reproduce with high definition extremely small and shallow flaws or steps in the interior surface of the experimental mold.

The plaster mold used in this experiment was made as follows:

Five parts "Ceramical" and two parts water were mixed approximately 30 minutes with a power mixer until the mixture became thick and creamy. The mixture was then poured into a mold pattern in which was suitably positioned the fiberglass tubing, this tubing being arranged to lay about $\frac{3}{4}$ inch below the working surface of the mold. The mold was allowed to set for ten minutes after which a small amount of air was blown through the fiberglass tubes to purge the mold.

The schematic illustrations in Figures 2 and 3 are intended to illustrate the broader aspects of the invention. In Figure 2, a mold 100 is held closed by a set of clamps 101. Clay slip is injected into the mold at about 750 p.s.i. through the line 102, water of suspension and shrinkage water being removed from the injected matter and particle orientation further minimizing the moisture residue as above described. Following this step, the clamps are released, the mold is opened, and the molded piece 105 is removed from the mold as shown in Figure 3. In general, with the slip compositions I have worked with, molding pressures may vary upwardly from about 600 p.s.i., with the presently most feasible pressures, from the standpoint of original cost and maintenance cost of presently available components, on the one hand, and results and production time on the other, having a practical top limit in the neighborhood of 1,000 p.s.i.

The pumping means employing the diaphragm-tank 15 illustrated in Figure 1 was provided to overcome the extreme problems of erosion and wear which arise when bearing surfaces are subjected to clay slip, particularly when such exposure occurs under high pressure. Other pressure systems adapted to handle highly abrasive fluids or semi-fluids may be employed, although the illustrated system appears to be well adapted to the intermittent type of operation employed in the illustrated embodiment.

The advantages of the invention from the standpoint of ware decoration should be mentioned. The inner surfaces of the open porous mold may be spattered before closing with a colored slip producing a spatter effect in the final product. The same effect may be achieved by injected colored slip into the closed mold prior to introduction of the main body of slip, such colored slip being introduced either under very high direct pressure or with compressed air. Marbleized designs may be obtained through the alternate injection of slips of different colors.

The invention is broadly applicable to the production of all types of ceramic shapes, including bricks, tiles, sanitary ware and other ceramic products in addition to pottery ware. The several variations thereof described above will demonstrate that the scope of the invention extends beyond the details of the specific embodiment which I have practiced and herein disclosed and will make it clear that the scope of the invention is not limited by the precise details of such specific embodiment. What I claim as my invention is defined in the following claims.

What is claimed is:

1. A process for making green ceramic objects which comprises transforming a ceramic slip composition to a non-fluid state by injecting said composition into a closed sectional water-permeable mold under a pressure sufficient to express both water of suspension and substantially all shrinkage water through the shaping faces of said mold, whereby preshrunk green ware of the shape of said mold is formed within said mold, thereupon releasing said pressure and opening said mold to remove therefrom, still in preshrunk condition, the formed green ware.

2. A process for making green ceramic objects which comprises transforming a ceramic slip composition to a non-fluid state by injecting said composition into a closed sectional permeable mold, the faces of which pass the water in the slip but prevent the escape of solid ingredients of the slip, under a pressure sufficient to express both

water of suspension and substantially all shrinkage water through the shaping faces of said mold, whereby preshrunk green ware of the shape of said mold is formed within said mold, thereupon releasing said pressure and opening said mold to remove therefrom, still in preshrunk condition, the formed green ware.

3. The method of making green ceramic objects comprising the steps of providing a slip, injecting the slip under pressure into a closed sectional permeable mold, the faces of which pass the water in the slip but capture for agglomeration the solid ingredients of the slip, and continuing pressure injection of the slip under a pressure high enough to express substantially all shrinkage water as well as water of suspension from the agglomerating solid ingredients of the slip, whereby preshrunk green ware of the shape of said mold is formed within said mold, thereupon releasing said pressure and opening said mold to remove therefrom, still in preshrunk condition, the formed green ware.

4. A process for making green ceramic objects comprising the steps of providing slip capable of fluid flow when subjected to pressures above a given value whether or not capable of fluid flow when subjected to pressures below said given value, injecting the slip under pressure above said given value into a closed sectional permeable mold, the faces of which pass the water in the slip but capture for agglomeration the solid ingredients of the slip, and continuing pressure injection of the slip under a pressure sufficiently above said given value to express substantially all shrinkage water as well as water of suspension from the agglomerating solid ingredients of the slip, whereby preshrunk green ware of the shape of said mold is formed within said mold, thereupon releasing said pressure and opening said mold to remove therefrom, still in preshrunk condition, the formed green ware.

5. A process for making green ceramic objects which comprises transforming a ceramic slip composition to a non-fluid state by injecting said composition into a closed sectional water-permeable mold under a pressure sufficient to express both water of suspension and substantially all shrinkage water through the shaping faces of said mold, whereby preshrunk green ware of the shape of said mold is formed within said mold, thereupon performing the terminal operations of releasing said pressure and opening said mold, and blowing moisture back to the shaping faces of said mold incident to said terminal operations to effect ready release and removal from the mold of the formed green ware, still in preshrunk condition.

6. A process for making green ceramic objects which comprises transforming a ceramic slip composition to a non-fluid state by injecting said composition into a closed sectional permeable mold, the faces of which pass the water in the slip but prevent the escape of solid ingredients of the slip, under a pressure sufficient to express both water of suspension and substantially all shrinkage water through the shaping faces of said mold, whereby preshrunk green ware of the shape of said mold is formed within said mold, thereupon performing the terminal operations of releasing said pressure and opening said mold, and blowing moisture back to the shaping faces of said mold incident to said terminal operations to effect ready release and removal from the mold of the formed green ware, still in preshrunk condition.

7. The method of making green ceramic objects comprising the steps of providing a slip, injecting the slip under pressure into a closed sectional permeable mold, the faces of which pass the water in the slip but capture for agglomeration the solid ingredients of the slip, and continuing pressure injection of the slip under a pressure high enough to express substantially all shrinkage water as well as water of suspension from the agglomerating solid ingredients of the slip, whereby preshrunk green ware of the shape of said mold is formed within said mold, thereupon performing the terminal operations of releasing said pressure and opening said mold, and blow-

ing moisture back to the shaping faces of said mold incident to said terminal operations to effect ready release and removal from the mold of the formed green ware, still in preshrunk condition.

8. A process for making green ceramic objects comprising the steps of providing slip capable of fluid flow when subjected to pressures above a given value whether or not capable of fluid flow when subjected to pressures below said given value, injecting the slip under pressure above said given value into a closed sectional permeable mold, the faces of which pass the water in the slip but capture for agglomeration the solid ingredients of the slip, and continuing pressure injection of the slip under a pressure sufficiently above said given value to express substantially all shrinkage water as well as water of suspension from the agglomerating solid ingredients of the slip, whereby preshrunk green ware of the shape of said mold is formed within said mold, thereupon per-

forming the terminal operations of releasing said pressure and opening said mold, and blowing moisture back to the shaping faces of said mold incident to said terminal operations to effect ready release and removal from the mold of the formed green ware, still in preshrunk condition.

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