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A ceramic shell casting process with emphasis on materials and costs

Thomas J. Lawless
Southern Illinois University Edwardsville

A CERAMIC SHELL CASTING PROCESS WITH EMPHASIS ON MATERIALS AND COSTS.

by

Thomas J. Lawless

B. S. in Education, Southeast Missouri State College

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BY Thomas J. Lawless

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DEGREE OF Master of Fine Arts

Lawrence L. Marcell
Thesis Director

Don F. Davis
Faculty Chairman

Edw. 3/66

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INTRODUCTION

Ceramic shell molds have been developed by industry for precision casting of metal. This technique has not been generally adopted by sculptors for several reasons. The detailed literature on this subject is largely limited to bulletins published by the manufactors of ceramic shell materials and directed to metalurgists and foundrymen. They are written in technical language and have the added disadvantages of giving costs and specifications for larger quantities of materials than are necessary for the sculptor. Finally, many sculptors are unaware of the literature that is available.

The high cost of materials has been a deterrent to the wider use of ceramic shell casting in the studio. Jacques Schnier, Professor of Sculpture, University of California, Berkeley, has said:

> The ceramic shell mold, because of its high resistance to thermal shock, its strength, and its permeability has definite application to the casting of sculpture forms, either solid or hollow. Although the cost of material is very much higher than those used for solid investment, ceramic shell requires a great deal less than does the latter. The amount of mold refuse is negligible. Then there is the matter of its high fidelity to surface detail and texture. But perhaps the most attractive feature of all is the extremely short de-waxing and burn-out time which practically

closes the gap between making the mold and pouring the metal.[1]

In the preceding paragraph, the only negative statement made about ceramic shell casting is the relative high cost of material. It is the object of this paper to present information derived from technical bulletins and personal experimentation of ceramic shell casting as it pertains to the sculptor. A special emphasis will be placed on materials that are readily available at low cost. Descriptions of ceramic shell materials and the procedure for their use will be followed by tables developed in the following ways: first, an analysis of manufacturer's bulletins; second, the relation of information to the experience and need of the sculptor; third, the casting of approximately two hundred ceramic shell molds.

The Nalco Chemical Company, Metal Industries Division, Chicago, Illinois, markets a proven line of products for ceramic shell casting. Nalco materials will be used for the control element in testing other substances that meet the general requirements for ceramic shell molds. All materials will be evaluated by the results of their casting ability, price, availability, and ease of handling.

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[1] Jacques Schnier, "Ceramic Shell Molding for Sculpture Casting," Proceedings of the Third National Casting Conference, March, 1964.

CHAPTER I

THE BASIC ELEMENTS OF CERAMIC SHELL

Ceramic shell investment is composed basically of three elements: binders, fillers, and stuccos. Ceramic refers to the refractory materials used in the composition. The shell differs from traditional solid investments in that the refractory materials are used to coat in several layers the pattern to be cast. Each of the three elements will be discussed in relation to general composition and costs.

Binders

Binders for the ceramic shell are colloidal agents to which refractory flours are added to make the slurry into which wax patterns are dipped. The binding agent must not shrink or expand in drying and must maintain its adhesive properties throughout a high temperature range. The binders meeting these requirements best are those having a dispersion of colloidal silica. The colloidal silicas fall into two categories: one, an aqueous colloidal silicate or silica sol; two, an ethyl silicate.

Silica Sol

Silicic acid formed from sodium silicate by an ion exchange which removes the high fluxing sodium is a colloidal silica. It is commonly known as a silica sol and has millions of fine silica particles suspended in it. It forms a very stable and reliable binder. Manufactured by a number of chemical firms in the United States, the prices of silica sols range from $2.16 per gallon to $2.50 per gallon.

Two things should be considered when comparing prices of different manufacturers. The first consideration is the percentage of solution. Most manufacturers make a 30 per cent solution, adequate for ceramic shell. The second consideration is the number of silica particles in the solution. Those products with a higher number of particles are desirable because of their more efficient binding effect, and because the material can be extended by adding water.

Aqueous silica sols dry slowly as compared with ethyl silicates, requiring a longer time for investing the pattern. The drying time of any binder will be affected by the filler, the stuccoing material and the atmospheric condition of the room.

Ethyl Silicates

Ethyl silicates are minute particles of silica suspended in combinations of ethyl alcohol bases. They are excellent ceramic shell binders as they form a highly refractory material in combination with the proper fillers.

The preparation of the ceramic shell investment using ethyl silicates involves an acid hydrolysis process requiring a mutual solvent such as isopropyl alcohol. Isopropyl alcohol, water and an acid catalyst (concentrated hydrochloric acid) are first mixed, then ethyl silica is added to this solution. This combination creates a chemical reaction which causes its temperature to rise between 100 and 105 degrees Fahrenheit. Within one or two hours it will return to room temperature. At this point, the binder is ready to be mixed with a filler to form the dip-coat slurry.

Ethyl silicate binders form a ceramic shell which is even stronger in the green state than that formed by the silica sols. The evaporation of the alcohol in the ethyl silicate binders shortens the time between investment coats. This is a particular advantage when used in a core where drying is difficult.

Ethyl silicates are flammable and require good ventilation to prevent collection of alcohol fumes. These binders are less stable in storage than the silica sols and require a check of the pH Factor. (Potential of Hydrogen: an indicator of acidity or alkalinity through chemically treated pH paper.) As the solution approaches the neutral stage, a gelling condition occurs. Storage life can be extended if the material is kept refrigerated.

In using an ethyl silicate, the content of the filler is important. Traces of lime or other neutralizing agent will gel the slurry. This action can be checked by the addition of more acid.

When bought in fifty-five gallon quantities, ethyl silicates cost approximately $5.70 per gallon for a 40 per cent solution. A 30 per cent solution may be obtained at a lower cost.

Fillers

Fillers are refractory grains with a very low coefficient of thermal expansion. The filler is added to the binder to form a slurry into which the wax pattern is dipped. The filler must be fine and uniform in grain size for it reproduces the surface of the wax in the mold. At least 97 per cent of the filler material should pass through a U. S. Standard 200 mesh screen. The finer the filler, the more faithful the reproduction of the wax surface. If the filler grains are too coarse, not only will they affect the surface of the casting, but coarse grains also settle too quickly in the slurry.

The most commonly used filler is fused silica. Any refractory material with a low coefficient of thermal expansion and sufficient grain strength can be used. Such materials would include calcified aluminous fire clays, flint grain, calcined bauxite and mullite. All of these materials have the necessary qualities to form efficient slurries, and are considerably less expensive than the fused silica sold to sculptors specifically for ceramic shell investment. Prices of fillers vary from $27.50 per hundred pounds for fused silica to $4.50 per hundred pounds for a highly refractory fire clay.

Stuccos

Like the filler, stucco material is highly refractory with a low coefficient of thermal expansion. Fused silica, calcified aluminous fire clay, flint grain, calcined bauxite and mullite are used in considerably larger grain than that used for fillers. Grog is an excellent, inexpensive stucco material for small castings.

The first stucco coat must contain a fine grain, small enough to pass through a 30 mesh screen. The stucco is added to the wet slurry coat. Succeeding coats of stucco need a higher percentage of larger grains. The stucco material builds the shell and strengthens it by allowing the next slurry coat to adhere to the protruding grains, binding each coat to one another to form the ceramic shell.

The stucco material need not be a coarser grade of the same material used for the filler, but should have approximately the same expansion rate to prevent cracking of the mold. Fused silica costs $53.30 per hundred pounds in this grain size. Grog costs $3.00 per hundred pounds.

CHAPTER II

PROCEDURE FOR CASTING

Preparation of the Slurry

In preparing the slurry, a rough guide of two and one-half parts filler to one part binder by weight will give good results. The slurry should have a creamy consistency.

Filler is added to the binder in a steel container that has a cover. Flexible plastic containers are not advisable for containing slurry because the slurry that dries on the sides will crack off, contaminating the mixture. For mixing small amounts of slurry (up to one gallon), a one-quarter inch drill with a paint mixer attachment is effective.

If a large quantity of slurry is needed, and if it is to be kept overnight, an electrically timed mixing device must be installed to stir the slurry periodically. If not stirred, the filler will settle to the bottom of the container where it will harden. Small amounts of slurry can be kept for three days if they are stirred before each use.

A wetting agent is almost always needed in a slurry for the first coat. "Wetting agents can be described as substances which lower the interfacial tension between a liquid and a solid surface. Thus, they promote easier wetting of a solid by a liquid."[2] Because too much wetting agent tends to gel the slurry, it must be used sparingly. An average amount of wetting agent would be .05 per cent of the volume of the binder. In a gallon mixture, three or four drops of wetting agent is sufficient. The exact amount depends on the agent used. Ultrawet 60L, a product of the Atlantic Refining Company, is manufactured as a wetting agent. Liquid household detergents work well.

> For best results the slurry should be mixed for at least five hours prior to using. This will allow time for the slurry to reach equilibrium, that is, all of the particles will be fully wetted and the viscosity and specific gravity will remain relatively constant.[3]

The addition of the wetting agent will produce air bubbles. These bubbles can be eliminated by using a debubblizer (Dow Corning ANTIFOAM "B"), or by skimming them from the surface of the slurry. Once the ingredients have been mixed and allowed to stand, the slurry can be used. When applying the first slurry coat, it is an advantage if the pattern or model can be dipped into the slurry for an even, quick coating. If this is not practical, the slurry may be sprayed with a paint sprayer. When mass production

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[2]Charles R. Martens, _Emulsion and Water-Soluble Paints and Coatings_ (New York: Reinhold Publishing Corp., 1964), p. 43.

[3]_Investment Casting with Nalcoag, Colloidal Silica and Nalcast Fused Silica_ (Chicago: Nalco Chemical Co.), pp. II-5, II-6.

is not a critical factor, small amounts of slurry can be mixed and poured over the pattern.

It is important that the pattern be drained of excess slurry and that all bubbles be blown out or punctured. Air can be trapped in undercuts and indentations. If air bubbles are not eliminated, they will distort the surface of the casting by showing up, as small pimples of metal, often referred to as plus metal.

If the first slurry coat does not adhere to the wax, the pattern is either not clean enough, or more wetting agent is needed. If this does occur, it is better to rewash the pattern and start over before resorting to the addition of more wetting agent.

Stucco Coats

After the first slurry coat is drained, a coat of 30 mesh grain stucco is sprinkled over the wet surface. The succeeding coats of stucco can be a coarser grain (10 to 20 mesh).

Each coat must be dried before the next is applied, as incomplete drying will cause the following coat to slough off. The drying time can be shortened by using a fan or blower. Drying time will vary with the kind of materials used plus the atmospheric conditions of the room.

The number of coats needed for a good shell mold depends on the size of the pattern and can vary from four to eight coats. The shell may range from one-fourth to one-half inch in thickness.

Dewaxing the Mold

The shell must be thoroughly dried before the wax is removed. A simple kiln or burn-out furnace is used to remove wax from the molds. Before the kiln or furnace is heated, care must be taken that the molds stand firmly, and that they are raised off the kiln floor by fire brick or kiln furniture to allow the wax to flow out freely. Since the kiln will be hot when the molds are placed and removed, easy access must be considered.

A wax drain in the kiln floor is desirable, but not necessary to a complete burnout. The drain will eliminate heavy carbonization of the molds and the smoke that results when the wax burns in the kiln.

The kiln is preheated to 1500 degrees Fahrenheit and the molds are placed in it quickly with as little heat loss as possible. The high temperature is necessary to insure the instant flow of the surface wax. Its removal allows room for the remaining wax to expand without damage to the mold. If the temperature is not high enough, the wax will expand and crack the molds before it flows out. The kiln must have a good air supply for an oxidation firing. If the atmosphere in the kiln is reduction, the mold will not burn clean and a carbon residue will remain to affect the surface of the casting.

Twenty to thirty minutes is sufficient time for the wax to burn out. When the wax and carbon are removed, the mold becomes white. The mold is then removed from the kiln and can then be poured immediately. Most molds are poured unsupported; however, if there is any doubt as to the strength of the mold, or if it is cracked, it may be packed in dry sand in order to reinforce the mold for the thermal shock of molten metal. Care must be taken to keep sand out of the mold cavity.

Molds need not be cast immediately after burnout, as they can be stored and reheated for casting. The molds should be poured as soon as possible after burnout or re-heating. The high temperature of the mold reduces the thermal shock of the metal and reduces the chances of the mold cracking. The reheating of the mold also removes moisture that may have collected in the mold from the atmosphere during storage.

Cracks in the mold can be patched with slurry. If the mold breaks away from the sprue, pouring cup, or some other fragile part of the object, it can be repaired with fiberglas dipped in slurry and built up with several coats of slurry and stucco.

CHAPTER III

RESEARCH AND DATA

The basic prerequisites for ceramic shell materials are stated in Chapter I. The possible materials which meet these requirements in each area-- binders, fillers and stucco -- are numerous.

The expense of using all of the known products in tests was prohibitive, since the minimum purchase quantity of each material was one hundred pounds. It was necessary then to select a representative group.

First to be selected was Nalcoag 1030, a silica sol binder that has given proven results for fifteen years. The author has used it for approximately two hundred castings in the last two years. Nalcoag 1030 is a product of the Nalco Chemical Company, which also manufactures proven fillers and stuccos. They, too, were used for controls.

Since these proprietary materials work so well, it may be reasonably asked, why not continue to use them? The principal reason is that when purchased in less than ton or carload lots, the cost of these products is extremely high. Nalcoag 1030 is shipped in one-quarter drums, costing $37.50 per drum. The fused silica, Nalcast P-1W a filler, costs $27.56 per 100 pounds. The fused silica stucco, Nalcast S-2, costs $23.50 per 100 pounds. This amounts to a total price of $88.56, to which the costs of other products will be compared.

Ethyl silicate binders had not been used by the author, but are employed extensively by industry for refractory manufacture. Because of its availability, Silester OS, an ethyl silicate produced by Monsanto Chemical Company was chosen. The first two binders, Nalcoag 1030 and Silester OS, could be expected to produce good molds.

Since cost was a primary consideration, something other than costly commercial products was needed to test. The third binder selected was sodium silicate, commonly called waterglass. This material had been used for repairing pottery in ceramics, and used with fireclay to make hard-setting mortar for kiln chimneys. It was readily available at a reasonable price.

One other material having the colloidal properties required for a binder was methyl cellulose gum. This material was also known in the ceramics studio, where it was used to keep glazes in suspension. Since small quantities of methyl cellulose gum form a strong gum solution, the price was within reason.

In searching for fillers to compare with the control, many materials were possible considerations. Materials from the ceramics studio, and from refractory industry were considered. During the past year, the author had used calcined kaolin with reasonably good results. With this in mind, other calcined materials with a low coefficient of expansion were considered. In particular, those materials having a high alumina content, an excellent refractory element, were tried.

Calamo 210, an aluminous fire clay, calcined at a high temperature, was the first filler selected as a test material. It contains 41.6 per cent alumina and 52.8 per cent silica.

For the second filler, another calcined material, calcined bauxite, was selected. Calcined bauxite has an alumina content of 88.9 per cent; a silica content of 6.2 per cent.

The third test filler chosen was vitreous silica. It had many of the properties of the control product at one-third the cost.

The same considerations that determined the selection of fillers were used for the selection of stucco materials. The author had for some time used a variety of materials for stuccoing. Coarser sizes of the fillers proved to be very dependable. Grog, or ground fire brick, was finally selected for the stucco test material because of its low cost and ready availability.

To insure valid test results, certain precautions were taken in the handling of materials. The dry products were stored in separate plastic containers; liquids in covered steel containers. The mixing tool was cleaned after every use as not to contaminate the next slurry mixed.

The tables were organized with the following factors in mind. First, the trade name and manufacturer were listed to facilitate ordering, or obtaining more information. Second, the generic name was included in order that alternate products might be found. Third, storage and safety factors were considered to be of great importance in the prevention of injury. Fourth, packaging and cost were related as important considerations in the purchasing. Fifth, pre-mixing and drying were included as factors to be taken into account in relation to facilities and use.

Since the molds must be handled before and after firing, their strength is an important consideration in the selection of materials.

Procedures for selection of materials to be tested were made with the needs of sculptors in mind, rather than those of industry. The tests which follow are so evaluated. In each test the results are documented with photographs.

Test of Binder Materials

TABLE 1

BINDER: NALCOAG 1030

Trade name	Nalcoag 1030 (control)
Generic name	Silica sol
Manufacturer	Nalco Chemical Company
Storage stability	Excellent. Do not allow to freeze.
Safety	No volatile fumes or toxic odors.
Packaging	¼ drum, F.O.B. Chicago
Cost	$2.45 per lb. plus shipping
Pre-mixing	None needed
Drying	Slow, as compared with Ethyl Silicate
Shrinkage	Minimal, depends on filler
Mold strength, green	Good
Mold strength, fired	Good
Filler	Nalcast P-1W
Stucco	Nalcast S-2
Metal	Silicon bronze

The testing of Nalcoag 1030 presented no particular problems. The procedure recommended in Chapter II was followed.

The relief plaque in Plate I needed special attention to insure complete coverage. The edges of molds for reliefs are frequently weak, and must be given an extra coat of investment. They can also be reinforced with fiberglas dipped in slurry. The drying time was accelerated by the use of a small fan.

Nalcoag 1030 is a convenient binder to use. It is nonvolatile and nontoxic. Cored pieces are more difficult with silica sols, such as Nalcoag 1030, than with ethyl silicates because of the slower drying time of the aqueous base by capillary action. The ethyl alcohol bases dry by evaporation.

Syton FM is another silica sol similar to Nalcoag. It is produced by Monsanto Chemical Company and is shipped from Everett, Massachusetts, in fifty-five gallon drums. It was not tested, but is reported to be a dependable product.

In this test, the mold was poured unsupported. No cracking of the mold was observed. The pour resulted in an excellent surface on the cast piece. (Plate I)

TABLE 2

BINDER: SILESTER OS

Trade name	Silester OS
Generic name	Ethyl silicate
Manufacturer	Monsanto Chemical Company
Storage stability	Special formulation and refrigeration.
Safety	Volatile fumes, requires ventilation.
Packaging	55 gal. drum FOB Everett, Mass. 5 gal. drum \$0.56 per lb.-55 gal. drum \$0.675 per lb. - 5 gal. drum (1 gal. = 10 lbs.)
Pre-mixing	Necessary
Drying	Excellent
Shrinkage	Minimal
Mold strength, green	Excellent
Mold strength, fired	Excellent
Filler	Nalcast P-1W
Stucco	Nalcast S-2
Metal	Silicon bronze

To prepare Silester OS for use in the slurry, the following acid hydrolysis method was used:

Formulation

	by weight	by volume
Silester OS	60.9	57.0
Anhydrous isopropyl alcohol	32.9	42.0
Water	6.1	6.1
Hydrochloric acid (concentrated)	0.1	0.1
	100.0	105.2

1. Mix alcohol, water and acid in suitable container.
2. Add Silester OS with continuous stirring.
3. Solution can be used within one to two hours.
4. Solution should be stored in a tightly capped container. Refrigeration prolongs its life.

The above formulation for Silester OS is one of its drawbacks. When mixing these materials, excellent ventilation is important because of the alcohol content in the formula. A fume hood is desirable. Sparks from an electrical mixer could ignite the fumes. This material was mixed with an electric drill in a well ventilated room with no ill effects.

In Chapter I, "Binders," the storage problems of ethyl silicates are discussed and should be taken into consideration before ordering this material.

The quick drying by evaporation of the alcohol makes this an excellent binder for cored pieces. Rapid drying can be a disadvantage in large pieces as it leaves little time to apply the stucco.

The mold in the green state is extremely strong, making handling easier.

Other chemical companies manufacture ethyl silicate. One, Stauffer Chemical Company of New York, produces a line of hydrolyzed ethyl silicate binders under the trade name, "Silbond." This product can be purchased in five gallon quantities. The elimination of the acid hydrolysis formulation is an advantage to the sculptor. This product has the same hazards as Silester OS. The open cup flash point is

55 degrees Fahrenheit. This means that at normal room temperature, flammable and explosive vapors are emitted and precautions against use around open flame or sparks must be taken.

This mold was poured unsupported. No cracking of the mold was observed. The casting had an excellent surface. (Plate II)

TABLE 3

BINDER: SODIUM SILICATE

Trade name	None
Generic name	Sodium silicate (waterglass)
Manufacturer	Ceramic Color & Chemical Co.
Storage stability	Excellent (tight container)
Safety	Very safe
Packaging	1-5 gal. container (liquid)
Cost	$7.50 per gal.
Pre-mixing	Dilute with 30% water
Drying	Excellent
Shrinkage	Excessive
Mold strength, green	Excellent
Mold strength, fired	Excellent
Filler	Nalcast P-1W
Stucco	Nalcast S-2
Metal	Silicon bronze

Sodium silicate seemed to have all the properties of a good binder. The material was mixed and applied in the usual manner and had the advantage of rapid drying. The molds were exceptionally strong, but after the molds were burned out, excess shrinkage was observed in the area of the pouring cup. When attempting to pour these molds, it was discovered that the shrinkage had distorted the molds beyond possible use. This shrinkage was caused by the fluxing action of the high percentage of sodium in the material. It is not recommended for use. (Plate III)

TABLE 4

BINDER: METHYL CELLULOSE

Trade name	None
Generic name	Methyl cellulose gum
Manufacturer	Mallinckrodt Chemical Co.
Storage stability	Excellent, keep dry.
Safety	Very safe
Packaging	1 lb. bags
Cost	$3.95 per lb.
Pre-mixing	2 ozs. m.c.g. to 1 qt. water
Drying	Excellent
Shrinkage	Minimal
Mold strength, green	Good
Mold strength, fired	Very poor
Filler	Calcined bauxite
Stucco	Grog
Metal	None poured

Methyl cellulose had great adhesive and colloidal properties that seemed to make it an excellent binder, but the lack of silica to form a sinter, or conglomerate of fused non-metallic particles, caused it to lose all binding properties in burnout.

The molds crumbled and could not be poured. (Plate IV)

Summary of Binder Research

Of the four binders tested, only Nalcoag 1030 and Silester OS produced usable molds. The ethyl silicate base of Silester OS caused a faster drying time, particularly for cored pieces. Rapid drying required that the mold be stuccoed immediately.

The advantages of Nalcoag 1030 (silica sol) are: (1) no pre-mixing, (2) easier storage and (3) lack of volatile fumes.

Both silica sol and ethyl silicate binders are manufactured by a number of chemical companies under various trade names.

The pre-hydrolysed ethyl silicate, "Silbond," from Stauffer Chemical should be considered as an alternate to Silester OS. Syton FM from Monsanto should be considered as an alternate to Nalcoag if a silica sol is used.

While one of the main functions of these tests is to discover other materials at lower prices, it was found that the general cost range of the binders did not vary enough to make any significant contribution.

Tests of Filler Materials

TABLE 5

FILLER: NALCAST P-1W

Trade name	Nalcast P-1W
Generic name	Fused silica
Manufacturer	Nalco Chemical Co.
Packaging	50 lb. bags
Cost	$27.56 per 100 lbs. plus shipping
Screen analysis	100% passed 200 mesh 75% passed 325 mesh
Shrinkage	Minimal
Mold strength	Good
Binder	Nalcoag 1030
Stucco	Nalcast S-2

Nalcast P-1W is a proven ceramic shell filler material. There were no problems observed in its use. The material mixed readily with the binder to form a slurry of even consistency. The slurry covered the wax evenly, and did not wash out when the metal was poured. Nalcast P-1W produced a good surface on the cast piece. (Plate V)

TABLE 6

FILLER: CALAMO

Trade name	Calamo 210
Generic name	Calcined aluminous fire clay
Manufacturer	Harbison-Walker Co.
Packaging	100 lb. bags
Cost	$4.50 per 100 lbs., plus shipping
Screen analysis	97% passed 200 mesh
Shrinkage	Minimal
Mold strength	Good
Binder	Nalcoag 1030
Stucco	Grog

Calamo 210 met all requirements for a filler in ceramic shell molds. It mixed well with the binder and covered the pattern evenly. Calamo's cost represents a saving of 84 per cent when compared to the cost of the fused silica used in the control. Good surfaces resulted on the casting. (Plate VI)

TABLE 7

FILLER: CALCINED BAUXITE

Trade name	None
Generic name	Calcined bauxite
Manufacturer	Harbison-Walker Co.
Packaging	100 lb. bags
Cost	$10.06 per 100 lbs., plus shipping
Screen analysis	88% passed 200 mesh
Shrinkage	Minimal
Mold strength	Good
Binder	Silester OS
Stucco	Grog

This highly refractory material contains 89 per cent alumina. Calcined bauxite combines well with ethyl silicate or silica sol binders. The bauxite flour produces fine surfaces, and represents a saving of 64 per cent compared to the control factor, fused silica. (Plate VII)

TABLE 8

FILLER: VITREOUS SILICA

Trade name	None
Generic name	Vitreous silica
Manufacturer	Harbison-Walker Co.
Packaging	100 lb. bags
Cost	$9.65 per 100 lbs.
Screen analysis	150 mesh plus fines
Shrinkage	Minimal
Mold strength	Good
Binder	Nalcoag 1030
Stucco	Grog

Vitreous silica met all requirements for a good ceramic shell filler. It mixed well with the binder and covered the wax evenly. No washing out or cracking of the mold was observed. Vitreous silica represents a saving of 65 per cent as compared with the control filler. The results of the casting were also of high quality. (Plate VIII)

Summary of Filler Research

All the materials tested for fillers proved satisfactory. The surface of the metal after each pour was good. Other fillers meeting the requirements for ceramic shell are calcined kaolin, mullite and zircon. Zircon, which is highly refractory in comparison to the refractory materials mentioned in the tests, is used by steel mills for pouring ferrous metal. It withstands thermo-shock well and has a low rate of thermo-expansion. While most of the materials tested could withstand the higher temperatures of ferrous casting, zircon is particularly advisable.

Tests of Stucco Materials

TABLE 9

STUCCO: NALCAST S2

Trade name	Nalcast S2
Generic name	Fused silica
Manufacturer	Nalco Chemical Co.
Packaging	50 lb. bags
Cost	$23.30 per 100 lbs.
Screen analysis	6% on 20 mesh 86% on 50 mesh 8% passing 70 mesh
Shrinkage	Minimal
Mold strength	Good
Binder	Nalcoag 1030
Filler	Nalcast P-1W

Nalcast S2 produced strong, dependable molds. There were no apparent problems in using the material or in the finished casting. The only disadvantage of this product is its high cost.

TABLE 10

STUCCO: GROG

Trade name	Grog
Generic name	Ground fire brick
Manufacturer	H. K.Porter Co.
Packaging	100 lb. bags
Cost	$3.30 per 100 lbs.
Screen analysis	12 screen and fines
Shrinkage	Minimal
Mold strength	Good
Binder	Nalcoag 1030
Filler	Calamo

Grog can be ordered in a large variety of sizes. Most grog includes the fines along with the coarser material. If such material is purchased, the fines may be screened out and used for the first stucco coat. The coarser material is used on the remaining coats and the finer grog can be applied on top of the coarse coats to fill and strengthen the shell.

Grog is a dependable, readily available stucco material. Its cost represents a saving of 86 per cent as compared to the control material.

Summary of Stucco Research

For stuccos, coarser sizes of the filler material can be used. The stucco should be a blend of fine and coarse grains for maximum strength. The first coat must have a fine grain size for better reproduction. Larger grains used in following coats achieve rapid buildup. Flint grain, mullite and Calamo may be used, but grog is as dependable and more economical.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

The tests have proven that there are numerous alternate materials for fillers and stuccos that greatly reduce the cost of ceramic shell investment. Binders are limited to ethyl silicates and silica sol. No reduction in their costs was found.

On the basis of price and convenience, the best results were obtained by the use of Nalcoag 1030 as a binder with Calamo 210 and grog as filler and stucco. The cost of investing a six inch figure using these materials is approximately forty-five cents. If the control fillers and stuccos are used to cast the same sized figure, the cost is approximately $1.25, or about three times greater.

The major difficulty encountered in the running of these tests was that of obtaining small amounts of materials. Syton FM, a silica sol similar to Nalcoag 1030, was not tested because the smallest quantity available was a fifty-five gallon drum, and a similar problem exists with Nalcoag 1030, whose minimum quantity is one-quarter drums.

A large part of the cost of the refractory materials proved to be the expense of shipping. The sculptor should try to find indigenous products or those which can be purchased from local manufacturers to reduce this cost.

Consideration should be given to further research into the problems of casting large, hollow pieces using the ceramic shell technique.

These problems were not considered in this paper. Since many molds were needed for the testing of material, only small molds were used. The cost and time involved in working larger pieces with untested materials was prohibitive.

The development of improved techniques for pouring slurry or inexpensive mixing equipment for maintaining large batches of slurry would be of great benefit to the sculptor.

It is hoped that the tests introducing additional ceramic shell materials together with their costs will encourage sculptors to use the process more extensively.

PLATES

PLATE I

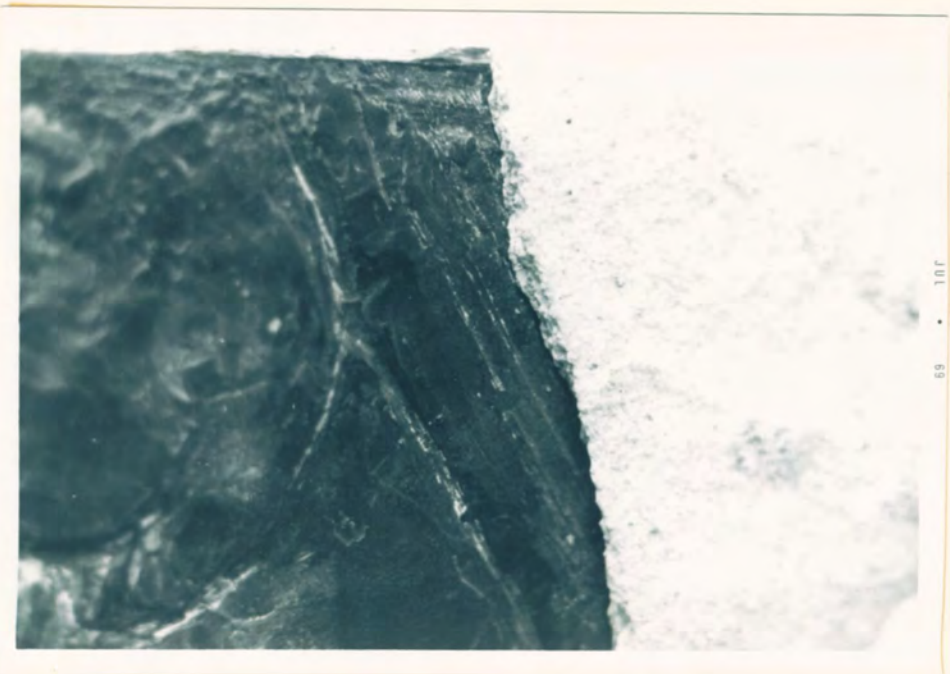

PLATE II

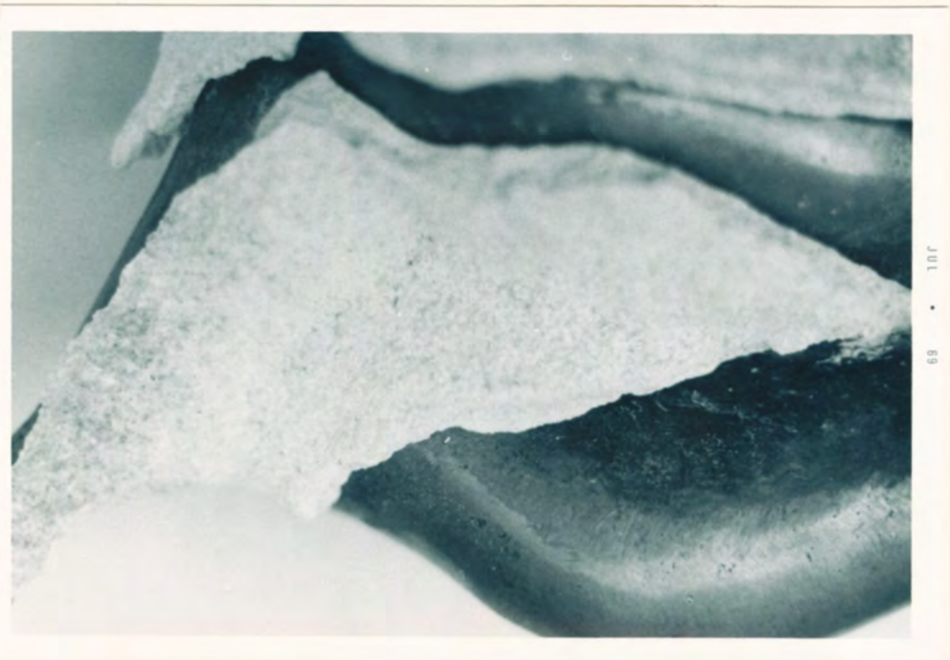

PLATE III

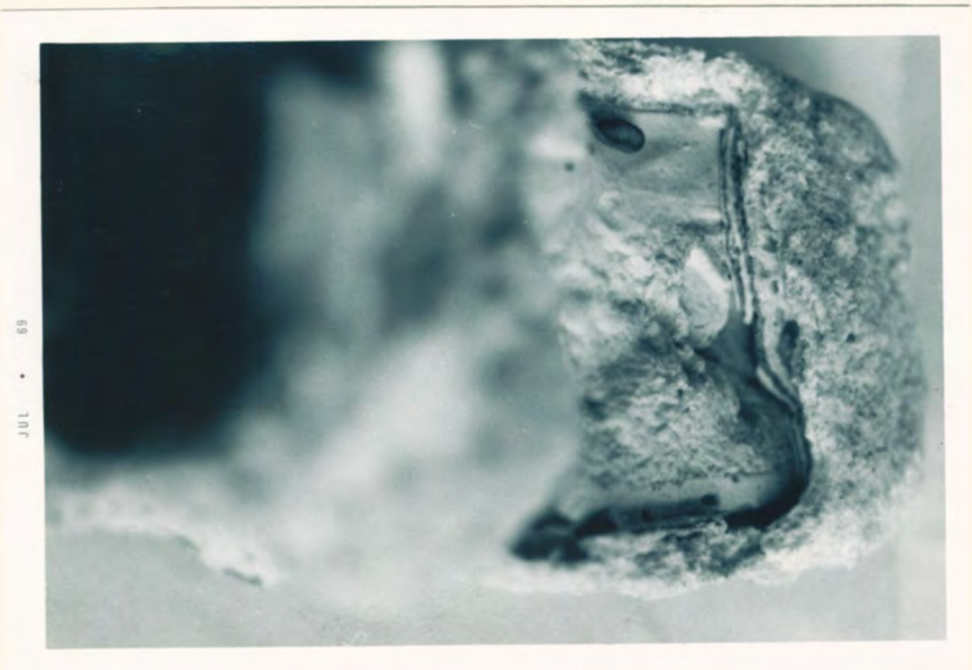

PLATE IV

PLATE V

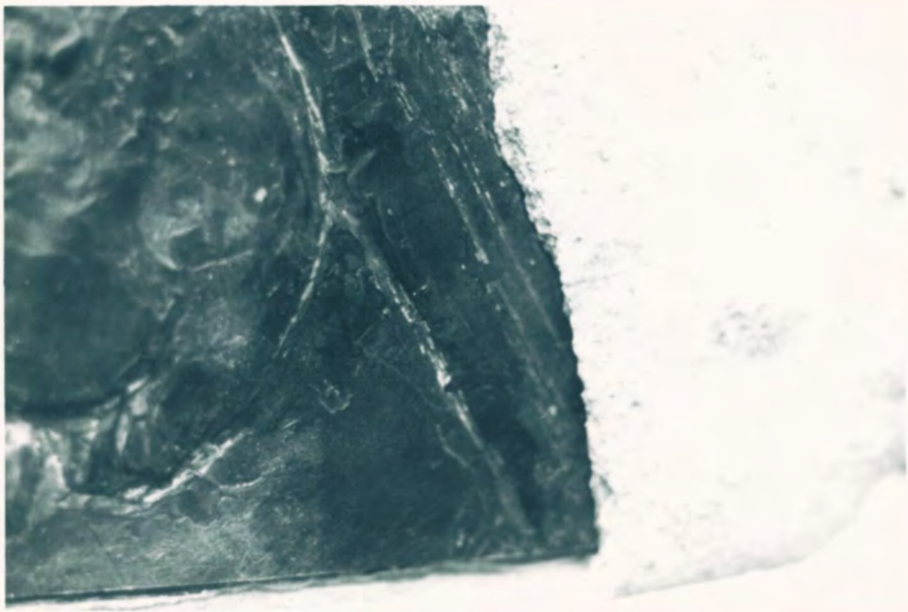

PLATE VI

PLATE VII

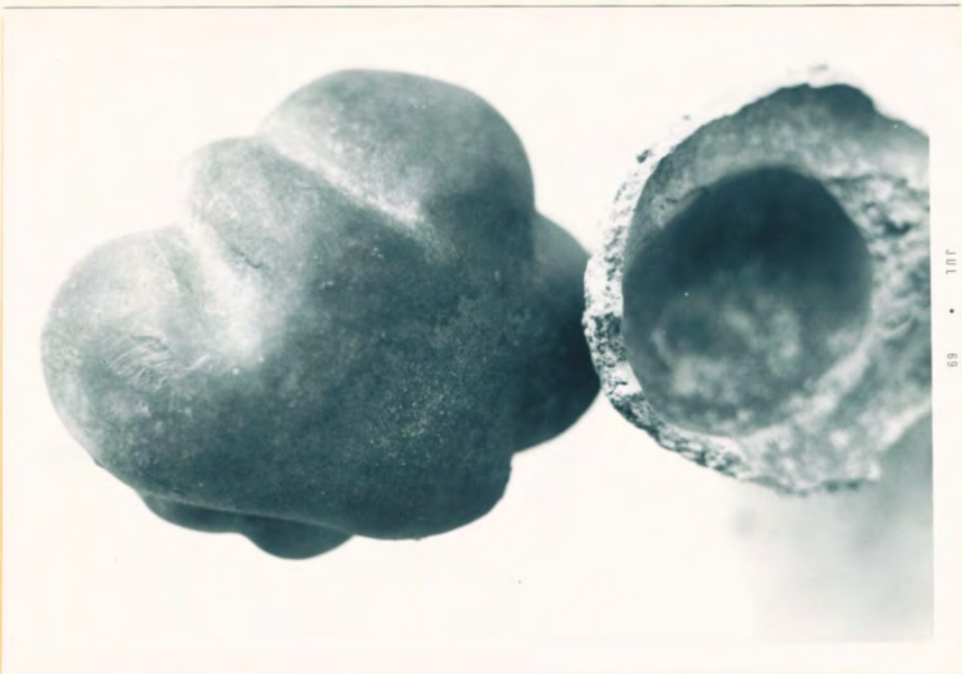

PLATE VIII

PLATE IX

PLATE X

APPENDIX

APPENDIX

SOURCES FOR CERAMIC SHELL MATERIALS

Binders:

Monsanto Chemical Co.
800 N. Lindbergh Blvd.
St. Louis, Mo. 63166
(314) OX4-1000

Stauffer Chemical Co.
Specialty Chemical Div.
299 Park Ave.
New York, N.Y. 10017
(212) 421-5000

Nalco Chemical Co.
Metal Industries Div.
9165 S. Harbor Ave.
Chicago, Ill. 60617
(312) 731-3020

Refractory Materials:

A. P. Green Products
1102 20th St.
Granite City, Ill.
(618) 451-9660

H. K. Porter Co.
4705 Ridgewood Ave.
St. Louis, Mo.
(314) 832-4900

Harbison-Walker Refractories
411 N. Seventh St.
St. Louis, Mo.
(314) 421-4890

Wax:

Mobil Oil Co.
125 Potomic St.
St. Louis, Mo.
(314) 865-2206

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Silester OS, Technical Bulletin 9S/4. London: Monsanto Chemical Co., 1959.

Struppeck, Jules. The Creation of Sculpture. New York: Holt, Rinehart and Winston, 1952.

Syton FM Product Profile. St. Louis: Monsanto Chemical Co., 1968.

VITA SHEET

Graduate School
Southern Illinois University
Edwardsville Campus

Thomas J. Lawless — Birthdate: May 7, 1930

7209 Waterman

University City, Mo. 63130

Degrees earned:

B.S. in Education, Art — Southeast Missouri State College
1956-59

Thesis Title:

A CERAMIC SHELL PROCESS WITH EMPHASIS ON MATERIALS AND COSTS
Adviser:
Larry Marcell, Assistant Professor of Art

Publications:

"Cire Perdue Process - Ninth Grade Level," Show-Me-Art, Fine Arts Bulletin for Teachers, March, 1962.

"Textured Tempera," Show-Me-Art, January, 1963.

"Aluminum Casting Process," Reynolds Aluminum Progress, (Reynolds Metal Company, September, 1967).

"A Demonstration of Sculpture Casting," KMOX-TV: CBS Montage Program, May 8, 1967. Mark Russell, Executive Producer.