A practical method to determine meaningful permeability values for ceramic shell moulds used in the bronze casting process

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This paper proposes a pragmatic means to evaluate the degree of permeability of different ceramic shell moulds using a low cost practical method as compared to a more sophisticated hot permeability method. The proposed method makes use of a blind riser as a "barometer" strategically attached to a mould to measure the different heights attained by molten bronze when poured into the mould in question. By arithmetic calculation the height of the bronze column in the blind riser gives an indication of the permeability of the ceramic shell mould under investigation. The permeability values thus obtained could be useful as an indicator to determine the number of risers that will provide sufficient air-vents for the moulds during a bronze pour.

Generally speaking, small art bronze casting studios in South Africa do not have easy access to hot permeability testing (cf. p. 8 definition of terms), which makes use of sophisticated equipment requiring a high degree of technical skill to operate successfully to determine the permeability of their ceramic shell moulds for bronze casting (cf. Guerra 1991: 8).

Testing the ceramic shells for permeability at room temperature gives a fair indication of what the permeability of the ceramic shell mould should be compared to the hot ceramic shell mould values. However it does not give a working indication of the permeability of the ceramic shell mould during the hot molten bronze casting process.

A number of factors that can affect the permeability of the ceramic shell mould to the residual air and the evolved gases derived from the molten bronze during each bronze pour are listed as follows:

- The type of bronze used

- The degassing method and technique used

- The height from which the bronze is poured

- The bronze casting temperature

- The mould temperature at time of pour

- The mould pouring-cup entry design, which could entrap air.

Previously it was naively assumed that the porosity of the ceramic shell moulds was also an indication of the permeability of the moulds (cf. Young and Fennel, 1980: 28). However only after repeated testing for permeability on a whole range of ceramic moulds, was it realized that the ceramic shells moulds were not as permeable as they were originally thought to be. (cf. Jones, 1999: 120).

Figure 1

A wild dog that was used as a model for the determination of permeability in conjunction with the ceramic shell mould casting method

Here it was assumed that the loss of permeability was due to the pores of the ceramic shell becoming blocked or clogged by undiluted or concentrated colloidal silica sol used as a wetting agent between the various layers of the shell during the shell mould construction process (cf. Lomax, 2001: 76).

In a casting environment, which does not have access to a hot permeability-testing instrument, it became necessary to develop a more pragmatic technique to determine the permeability of the ceramic shell at the time of the bronze pour.

During his *Magister Technologiae*: Fine Art (M Tech FA) studies, the author performed numerous permeability experiments on ceramic shell formul-

ations. The ceramic shell could be made porous yet practically impermeable, depending upon the shell formula and the building technique used. This phenomenon led the author to develop the blind riser or "barometer" technique (Lomax 2001: 99).

The "barometer" or blind riser technique:

The basis for the theory of using a blind riser or "barometer" to replace the more expensive and technologically advanced hot permeability testing method is as follows: A blind riser is attached to a moulded wax test piece (a model of a wild dog was chosen in this regard (cf. figure 1). At the lowest practical extremity from the pouring cup (cf. figure 2). As molten bronze enters the mould made from the wax test piece, it fills the blind riser from the bottom, forcing air present in the riser to permeate through the ceramic shell. The length of the column of bronze left in the blind riser or "barometer" after the bronze has set, indicates the degree of permeability of the particular ceramic shell under investigation. It must be emphasized that the test pieces should have the same dimensions in each case (the reason for a moulded wax test piece) so as to make the permeability of the different ceramic shells under investigation as comparable as possible

The diagram of the wild-dog in cross section (see figure 2 below), illustrates a single feeder and the absence of gas vents, and was used as a standard model for permeability testing (cf. Lomax, 2001: 14). The blind riser is 10 cm long and 0,3 cm thick. The diameter of the riser is not critical for the test, but it must have the same diameter and length in each comparable test. All the variable

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ceramic shell mould parameters (for a particular bronze foundry) used in mould construction and bronze pouring should be as unified as possible for each permeability test mould under investigation.
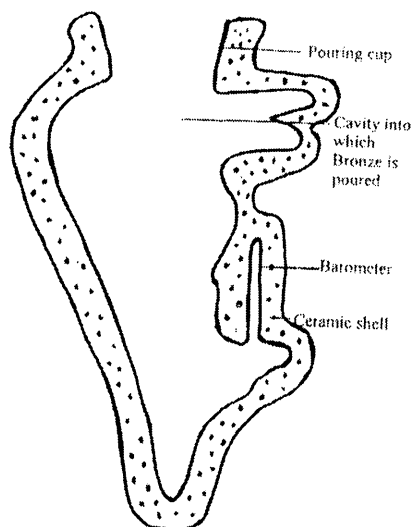

Figure 2
Diagram of the wild-dog test piece.

The results illustrated below (cf, Lomax: 2001: 99), gives an indication of how the permeability can be changed by altering the composition of the slurry formula (cf. definition of terms). The porosities of the ceramic shell moulds were also measured at room temperature as a comparative indicative value to the height of bronze in the "barometer".

Empirical testing procedure:

The ceramic shell mould was built around the wild-dog wax model with the blind riser "barometer" as indicated in the diagram above.

The ceramic shell mould making:

The wax model is dipped into the test slurry (cf. table 1) and a stucco layer is applied using 100 mesh chamotte as the stucco medium, called dip 1. The mould is now allowed to dry for up to four hours in a controlled environment to ensure uniformity and complete drying. Dip 2, is again a repeat of this process. Dip 3 to 7 are repeats of this process, except that the finer 100-mesh chamotte is replaced with coarser 0,25-0,7mm chamotte. The completed ceramic shell mould is allowed to dry for a minimum of 24 hours after which time the ceramic shell mould is ready for de-waxing and sintering in an electric kiln.

The method employed for de-waxing and sintering the ceramic shell mould:

An electric kiln is heated to 500^0C. The ceramic shell mould is introduced into the hot kiln where the wax rapidly melts out of the mould without cracking the ceramic shell mould (cf. Penland, 1976: 39). The ceramic shell mould can now be safely sintered to 950^0C. The process of rapid de-waxing the ceramic shell mould is known as "flash de-waxing". The molten bronze is poured into the mould whilst the ceramic shell mould is still hot (having first been removed from the kiln). The pouring temperature of the molten bronze is between 1175^0C and 1200^0C (cf. Jones, 1999: 87). After pouring the bronze into the ceramic shell mould, it is allowed to cool. Once the ceramic shell mould has cooled to room temperature it is now broken away from the solidified bronze.

The "barometer" or blind riser height is now measured as follows: The height of the bronze in the pouring cup is noted and the height is corrected for in the

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subsequent tests as the variations in this height can affect the height of the bronze in the blind riser. See wild-dog measurements in the diagrams below (cf. Lomax, 2001: 16).

Porosity determination:

The method used for porosity determinations was to accurately weigh the ceramic shell mould in air to 0,100 gm. The ceramic shell mould was then immersed in de-ionized water for one hour to allow the ceramic shell mould to become completely saturated. The saturated ceramic shell mould was removed from the water and the lightly dried with a lint free cloth or a clean dry sponge to remove any excess surface water from the mould. Using a thin cotton thread (tied to the ceramic shell mould so it can hang freely), the mould was suspended from the balance and weighed. The water saturated ceramic shell mould attached to the scale-arm by the cotton thread was then lowered and duly immersed in a suitable glass beaker containing sufficient de-ionized water to completely cover the suspended mould. The weight of the ceramic shell mould in water was recorded to the nearest 0,100 gm. The formula for the porosity of the ceramic shell mould was determined as detailed below (cf. Chesters 1983: 475):

$$\frac{\text{Wet weight} - \text{dry weight} \times 100}{\text{Wet weight} - \text{weight in water}} = \% \text{ porosity}$$

Limitations of the method:

The limitations of this test procedure illustrates that it is not a definitive analysis of the permeability of the ceramic shell mould, nor is it directly comparable to hot permeability testing,

but it does give a good repeatable indication of how the ceramic shell mould allows unwanted gases to be expelled from the hot mould.

Variables that can affect the "barometer" height:

Cognizance should be taken of certain variables when comparing one set of results with the next. The variables are listed below:

- Type of bronze used

- Pouring temperature of the bronze

- The height from which the molten bronze is poured

- Degassing techniques (cf. Jones, 1999: 76)

- Final sintering temperature of the ceramic shell mould

- The diameter of the "barometer" tube

- The height of the "barometer" tubes

- The total height of the poured bronze.

For comparative values of permeability, these factors must be borne in mind, especially when different size bronzes are poured. The following table 1 (cf. Lomax, 2001: 102) and figure 3 were taken from a set of tests conducted at the Port Elizabeth Technikon sculpture foundry studio by the author.

	Slurry Formula 1	Slurry Formula 2	Slurry Formula 3
Levasil	40	30	20
Water	-	10	20
Chamotte	60	60	60
Porosity	14,5%	17,1%	19,5%
Length of "barometer"	2,9cm	3,7cm	5,2cm

Levasil = Levasil 4063
Water = de-ionized water
Porosity = mould sintered to 950^0C and evaluated at room temperature.

Table 1

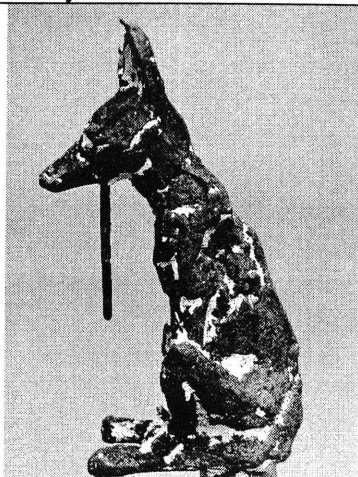**Slurry formulae with corresponding porosity and "barometer" heights**

Wild-dog bronze from slurry formula 1	Wild-dog bronze from slurry formula 2	Wild-dog bronze from slurry formula 3
"Barometer" height ,9cm.	"Barometer" height 3,7cm.	"Barometer' height 5,2cm.

Figure 3
The comparative lengths of the bronze "barometers" on three castings made respectively with slurry formula 1,2 and 3.

Reading the "barometer":

Table 1 illustrates the results obtained for a specific bronze pour using the ceramic shell mould building process outlined above. It was found that the lower the concentration of Levasil 4063 (a branded colloidal silica sol cf. def. of terms), in the slurry under investigation, the greater the porosity measured for that particular ceramic shell mould. It will be noted the porosity values are not directly related to the "barometer" heights obtained in these experiments. What is indicated is that the porosity of the ceramic shell mould increases as the concentration of colloidal silica sol is reduced with an increase in the permeability of the ceramic shell mould.

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Conclusion

The discussion above illustrates that the small bronze-casting studio can obtain meaningful comparative permeability figures for their ceramic shell moulds. The permeability results obtained from this method can also be used as an indicator of the number of risers that should be attached to the mould to act as air-vents during the bronze pour as well as a control to the ceramic shell building technique used in the small bronze studio.

Glossary

- Chamotte: also known as grog. A high fired aluminium silicate usually above 3000^0C, ground and graded to different mesh sizes.

- Levasil 4063: A colloidal silica sol that is used as a binder in the ceramic shell mould process. Produced by Bayer AG. Germany.

- Hot permeability testing method:

  Extract from the article: The effect of particle size of fused silica flour on shell properties, Investment casting Institute: 45th Annual Technical Meeting 1997, J.C. Niles Remet Development Laboratory, Utica, New York. The permeability samples are initially fired to approximately 71^0C to burn out the ping-pong ball. The temperature was then increased to 950^0C and held for one hour. The glass tube extends out through a small hole in the furnace door. A nitrogen source is connected to the glass tube using Tygon tubing. A manometer is then set for five cm of mercury and the flow read of the flow meter. The permeability number can be calculated using the following formula:

Permeability number =

$$\frac{(shell\ thickness)\ x\ (flow)}{190,000}$$

Sources cited

Chesters, J.H. (1983). Refractories Production and Properties. London: The Metal Society.

Guerra, M. (1991). A Study of the consistency of zircon flour. Unpublished company literature. New York: Remet Development Laboratory.

Jones, D.A. (1999). Bronze Casting. Unpublished M. Tech. F.A. dissertation. Port Elizabeth: Port Elizabeth Technikon.

Lomax, L.T. (2001). The Influence of Permeability and Porosity in the ceramic shell bronze-casting process. Unpublished M. Tech. F.A. dissertation. Port Elizabeth: Port Elizabeth Technikon.

Penland, L.C. (1976) Expanded Plastics used as Sculptural Patterns for Burn-Out in Ceramic Shell Moulds. Unpublished P.H.D. thesis. Denton: North Texas State University.

Young, R.D. and Fennel, R.A. (1980). Methods for Modern Sculptures. San Rafael: Sculpt-Nouveau.