A. Chennakesava Reddy,[1] V.S.R. Murti,[2] and P.M. Jebaraj[3]

A New Technique for Measurement of the Strength of Ceramic Shells in the Precision Casting Process

REFERENCE: Chennakesava Reddy, A., Murti, V.S.R., Jebaraj, P. M., "A new Technique for Measurement of the Strength of Ceramic Shells in the Precision Casting Process," Journal of testing and Evaluation, JTEVA, Vol. 28, No.3, May, 2000, pp.224-226.

ABSTRACT: This paper discusses the development of a new technique for measuring the strength of ceramic shells. In this technique, compressed air was passed into the ceramic shells and the bursting pressure was measured using a diaphragm pressure gage. The hoop stresses were calculated. The results of the new technique realistically match the actual failure rate of shells in the precision casting process.

KEYWORDS: ceramic shells, bending strength, permeability, bursting strength, failure rates.

In the manufacture of ceramic shell molds by the precision casting process, a multi-layered ceramic shell is built up by repeatedly dipping a wax pattern cluster in a dip-coating slurry, draining, and sprinkling with a coarse stucco sand. Each individual coat is hardened prior applying the next coat [1].

The ceramic shell molds are poured with liquid metal to produce precision castings. The ceramic shells, which are thin-walled molds, are generally subjected to metallostatic pressures and gas pressures. Metallostatic pressures vary due to the evaluation of gases during the solidification and the lack of permeability of the shells [2].

The strength of the shell under casting conditions relates to the ability of the shell system to retain the molten metal and maintain the dimensional integrity of the cast part. As casting temperatures, shell materials become plastic and flex or deform without failing, creating a thicker dimension in the casting than required. If the shell is not permeable enough, the resulting casting will have no fill where air was trapped in the casting [3, 4].

The present status of testing of ceramic shells is the measurement of their bending strength either at room temperature or at casting temperatures [5]. The bending strength of the shell is measured on a universal sand-strength testing machine (of hydraulic type).

This paper discusses the development of a new technique for measuring the strength of ceramic shells. In this technique, compressed air is passed into the ceramic shells and the bursting pressure is measured using a diaphragm pressure gage. The hoop stresses are calculated.

Experimental Procedure

Raw materials used:

Refractory filler	Zirconia flour, alumina flour and fused silica flour
Binder	Silox-30
Stuccoing sand	For prime coats (average particle size = 0.18 mm)
	For backup coats (average particle size = 0.32 mm)
Pattern	Bees wax

Manufacturing of Ceramic Shells

Ceramic shells were made by applying a series of ceramic coatings to the wax patterns. The pattern was first dipped into the dip-coating slurry. The dip-coating slurry was a mixture of refractory filler and liquid binder. The wet layer was immediately stuccoed with silica sand. Each coating was allowed to dry open air. The operations of coating, stuccoing, and drying were repeated six times. The seventh coat was left unstoccoed to avoid the occurrence of loose particles on the shell surface. The first two coats were stuccoed with a sand of 0.18 mm average particle size and the next four coats were with a sand of 0.32 mm average particle size. The shells were air dewaxed and sintered to 800°C.

Measurements of the bending strength and permeability of ceramic shells were conducted on a universal sand-strength machine and standard permeability meter, respectively. The dimensions of specimens used for bending tests are 25 by 32 by 5 mm. the bending test consists in determining the bending stress in N/mm^2 to cause rupture in the ceramic shell specimen. The dimensions of the permeability specimen are 38-mm internal diameter and 5-mm thickness. The specimen was connected with a hose pipe to the

\Manuscript received 09/20/99; accepted for publication 2/11/00.

[1]Department of Mechanical Engineering, M. J. College of Engineering and Technology, Banjara Hills, Hyderabad 500 034, India.

[2]Department of Mechanical Engineering, Osmania University, Hyderabad 500 007, India.

[3]Department of Mechanical Engineering, Dr. Ambedkar Institute of Technology, Bangalore, India.

standard permeability meter. Permeability was determined by measuring the time necessary for 2000 cm^3 of air to pass through the specimen under a pressure of 10 g/cm^3.

Specimens with dimensions equal to to those of the permeability specimens were employed to measure the bursting pressures of the shells. The experimental arrangement is shown in Fig.1.

A digital pressure gage was used to measure the bursting pressure of the shells. The specimen was connected to an air compressor with a hose pipe. The compressed air was allowed into the specimen. The pressure at which the shell burst was noted as the bursting pressure. The induced hoop stress were computed assuming the ceramic shell to be a thin-walled spherical shell. The formula used to determine the hoop stress in kgf/cm^2 [6] is given below:

$$\text{Hoop stress} = \frac{p.d}{4.t}$$

where

p = bursting pressure, kgf/cm^2

d = internal diameter of spherical shell, cm
= 3.8 cm

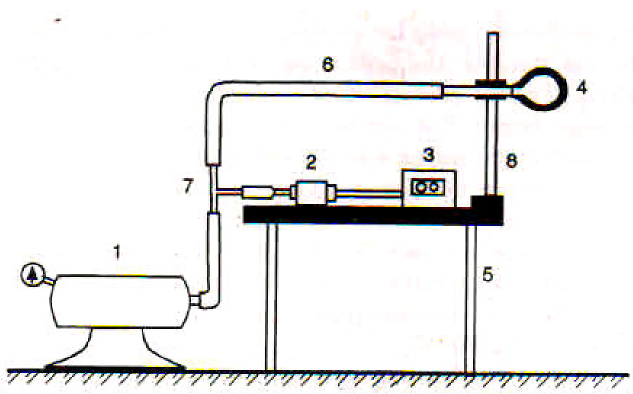
T = thickness of shell, cm
= 0.6 cm

[note 1 kgf = 9.8 N].

Results and Discussion

The experimental mean values and standard deviations of bending strength, permeability, and hoop stress of the shells are given in Table 1.

The permeability values of ceramic shells made of different refractory filler materials are illustrated in Fig.2. The permeability of zirconia shells is high, whereas alumina shells possess low permeability. The variation of permeability is due to the particle shape of refractory flour. Zirconia flour particles are round, alumina flour particles are angular, and fused silica particles are sunagular.



1. Air compressor, 2. Pressure gage, 3. Display unit, 4. Ceramic shell, 5. Table, 6. Hose pipe, and 7. T-connector

FIG. 1-*Experimental setup.*

Strength of Ceramic Shells

The bending strengths and hoop stresses of ceramic shells are shown in Fig.3. the bending strength of zirconia shell is low, whereas it is high for alumina shells. This is because zirconia shells

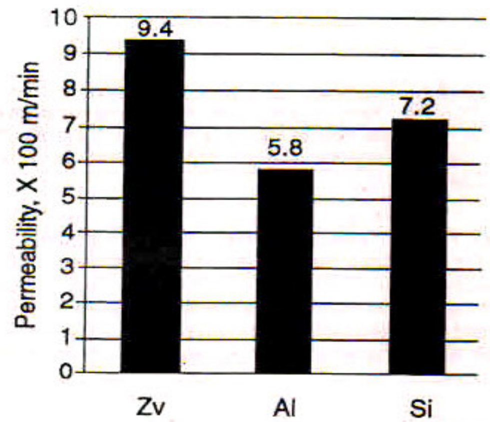


FIG.2-*Permeability values of shells.*

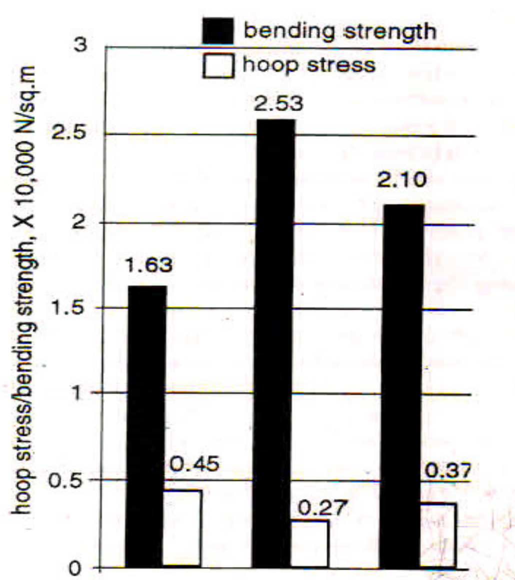


FIG.3-*Bending strengths and hoop stresses of shells.*

TABLE 1—*Results of tests.*

Shell	Bending Strength, × 1000 N/m^2		Permeability, × 100 m/min		Bursting Strength, × 1000 N/m^2	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Zirconia	1.63	0.14	9.4	0.12	0.45	0.06
Alumina	2.58	0.06	5.8	0.07	0.27	0.09
Fused silica	2.10	0.17	7.2	0.20	0.37	0.06

TABLE 2—*The failure rates.*

Shell	No. of Shells Broken Below Minimum Bending Strength	No. of Shells Broken Below Minimum Bursting Strength	No. of Shells Broken When Steel Cast into the Shells
Zirconia	3	5	5
Alumina	5	7	8
Fused silica	6	9	10

exhibit high permeability and alumina shells have low permeability. The increase of permeability in shells is directly proportional to the increase of voids in the shells. Voids in the shells decrease the strength of the shells.

The bursting strength (hoop stress) of zirconia shells is greater than that of alumina shells. This is due the fact that the compressed air leaks out from high permeability shells and consequently a greater pressure is needed to burst the ceramic shells. Gases and air result in the shells due to:

- Gases evolved due to the burning of the chemical binder
- Air trapped during the pouring of the liquid metal
- Gases released during the solidification fo the metal

If these gases accumulate, the shells fail even at low bending strength values, which are sufficient to withstand only metallostatic pressure.

The failure rates of the ceramic shells are given in Table 2. Twenty-five ceramic shells of each type were tested. The failure rate of the ceramic shells with hoop stress criteria approaches closely the failure rate of the shells when steel was actually cast into them. Hence, the results of the new technique realistically match the actual failure of the shells in the precision casting process.

Conclusions

1. The permeability of zirconia shells is greater than that of silica and alumina shells.
2. The lower the permeability of the shell, the higher the shell bending strength.
3. The higher the permeability of the shell, the greater the shell bursting strength.
4. The bursting strength value of the shell gives the actual shell failure rate in the precision casting process.

References

[1] Chennakesava Reddy, A., Babu, K. M., Jebaraj, P.M., and Chowdaiah, M. P., "Accelerator for Faster Investment Moulds," Indian Foundry Journal, Vol.41, No.10, 1995, pp.3-8.

[2] Chennakesava Reddy, A., Nirnajan, H.B., and Murti, A. R. V., "optimization of investment Shell Mold Using Colloidal Silica Binder," Indian Journal of Engineering and materials Sciences, Vol.3, No.5, 1996, pp. 180-184.

[3] Chennakesava Reddy, A., Murti, V. S. R., and Sundara Rajan, S., "Characterization of Dip-Coating Slurries from Coal-Flyash for Investment Casting Process," international Journal of Colloids and Surfaces, 1999, accepted for publication.

[4] Rusher, R. L., "Strength Factors of ceramic Shell Moulds," Cast Metal Research Journal, December 1974, pp.149-154.

[5] Dolman, J., "Standardization of Methods of Determining Permeability and Strength of Ceramic Shells," Foundry Trade Journal, Vol. 121, 1966, pp.724-727.

[6] Chennakesava Reddy, A., "Investment Casting Process Using Silox-30 as Binder," M.E. thesis, Department of Mechanical Engineering, Bangalore University, India, 1993.