

# **INVESTMENT SHELL MOULDS USING GRAPHITE FILLER TO PREVENT DIMENSIONAL INSTABILITY AND METAL-MOULD REACTION OF TI-ALLOY CASTINGS**

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**Abstract:** The ceramic shells were fabricated with ceramic slurry containing graphite as a filler material and colloidal silica binder. The linear expansion coefficient of graphite shells increases with temperature. The presence of a hard alpha case layer is observed beneath the surface of the casting.

**Keywords:** Investment shells, graphite, hot strength, thermal expansion, metal-mould reaction.

## **1. Introduction**

The materials used to build the investment shell moulds, especially refractories, play a vital role in the production of quality castings [1-6]. The properties of refractory fillers, which affect the shell quality, are melting point, thermal expansion, and metal - mould interaction. Under sizing of cast titanium crowns has been reported to be a problem. The diameter of standardized, cylindrical crowns was studied using a photographic technique and cold mould [7, 8]. The dimensional problem could be avoided by selecting a standard phosphate bonded investment with a sufficiently high thermal expansion coefficient. Appropriate casting conditions with a good vacuum (13.3 Pa) give only a thin (less than  $10 \times 10^{-6}$ m) oxide film and reproducible dimensions of the castings. A zircon coating eliminates or reduces the oxide film and follows the movements of the investment. The diameter of the crown can largely be accounted for by the measured expansion of the investment and thermal contraction of the Ti casting.

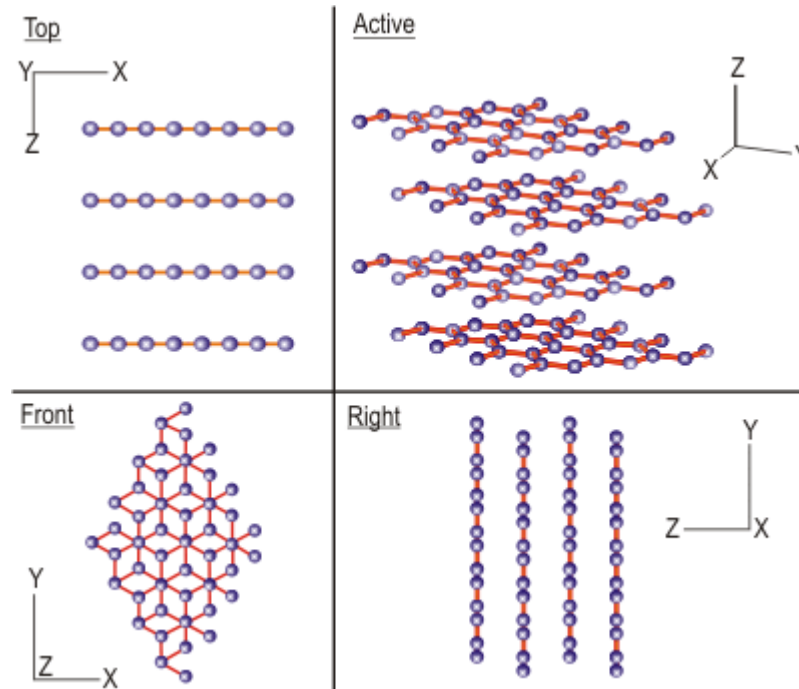
The objective of the present work was to prevent expansion of shell moulds and to reduce oxide film formation on Ti-alloy castings using graphite filler in the investment slurry.

## **2. Materials and Methods**

The colloidal silica binder was used to fabricate the ceramic shells from graphite as a reinforced filler material. The specifications of colloidal silica binder and graphite are, respectively, given in table 1 and table 2. Two grades (primary and backup sands) of stuccoing sand were employed in the present investigation.

In graphite the carbon atoms are arranged hexagonally in a planar condensed ring system (figure 1). The layers are stacked parallel to each other. The atoms within the rings are bonded covalently, whilst the layers are loosely bonded together by van der Waals forces. The high degree of anisotropy in graphite results from the two types of bonding acting in different crystallographic directions. For example, graphite's ability to form a solid film lubricant comes from these two contrasting chemical bonds. The fact that weak Van der

Waals forces govern the bonding between individual layers permits the layers to slide over one another making it an ideal lubricant.



**Figure 1.** Crystal structure of graphite.

**Primary sand:** A finer grade silica sand having AFS grain fineness number 120. This is a synthetic sand. This sand was used for first two coats, called prime coats to get good surface finish and every detail of the wax pattern.

Table 1. Specifications of silox binder

Property	Amount
Silica (SiO <sub>2</sub> ) Wt%	30
P <sup>H</sup> at 25°C	10.5
Titration Alkali (Na <sub>2</sub> O)	0.6
Chlorides/ Sulphates	Traces
Specific gravity, g/cc	1.23

**Backup sand:** A coarser grade sand having AFS grain fineness number 42. This sand was used for the rest of coats, called backup coats on the ceramic shells. This is a river sand. The backup sand was employed to develop more thickness to the shell walls with minimum coats.

Table 2. Specifications of graphite

Property	Graphite
Density, g/cc	2.16
Refractoriness, °C	3652
Chemical composition	C
Sieve analysis	200-mesh (74 μm)

### 2.1 Manufacture of ceramic shells and Ti-alloy castings

The investment shells were made of applying a series of ceramic coatings to the wax patterns. The pattern was first dipped into the dip-coating slurry bath. The pattern drains off excess slurry and to produce a uniform layer. The wet layer was immediately stuccoed with coarse silica sand. Each coating was allowed to dry in the open air. The operations of coating, stuccoing, and drying were repeated six times. The seventh coat was left unstuccoed to avoid the occurrence of loose particles on the shell surface. The first two coats were stuccoed with sand of AFS fineness number 120 and the next four coats were with sand of AFS fineness number 42. After all coats, the shells were air dried for 24 hours. Two shells of each treatment were made. The pre-heated investment shells were poured with Ti-alloy.

### 2.2 Hot strength of ceramic shells

The dimensions of specimens are 25mm X 32mm X t mm, where t is the thickness of the shell. The specimens used for bending test are shown in figure 2. The test of hot modulus of rupture was conducted on the universal sand- strength testing machine with attached electrical oven as shown in figure 2. The temperature of the oven was measured with a thermocouple attached to it. To find hot modulus of rupture, the ceramic shell specimens were heated to various temperatures and the same was tested simultaneously in the oven for the bending strength.

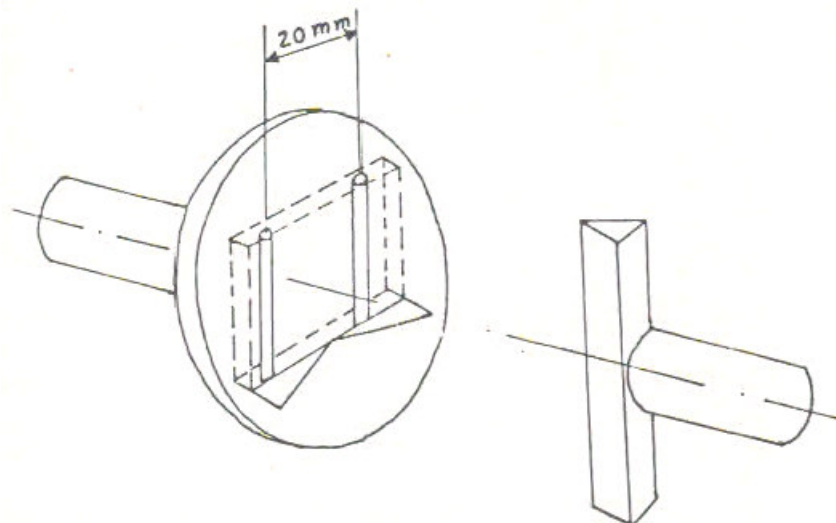


Figure 2. Hot bending strength test

### 2.3 % thermal expansion of ceramic shells

It was measured in terms of %volume expansion of the investment shells. The length, width and thickness of the shells were measured using vernier calipers before and after sintering in the electrical oven. The % thermal expansion was computed using the following formula:

$$\% \text{ thermal expansion} = \frac{V_2 - V_1}{V_1} \times 100$$

where,  $V_1$  is the volume of the shell before sintering and  $V_2$  is the volume of the shell after sintering.

### 2.4 Scanning electron microscopy (SEM)

SEM was carried out to characterize the fine-scale topography and establish the microscopic mechanisms governing metal-mould reaction. The scanning was carried in IISc (Indian Institute of Science - Bangalore) S-3000N Toshiba Scanning Electron Microscope.

### 3. Results and Discussion

The effect of sintering temperature on the hot bending strength of ceramic shells is shown in figure 3. The filler to binder ratio was 0.75 cc/ml. The hot bending strength of graphite shells decreases with increasing temperature. This is due to phase transformation of graphite at high temperatures. The phase diagram of carbon is shown in figure 4. There are at least two stable solid phases of carbon: from the structural point of view, graphite represents a crystalline hexagonal form, and diamond a tetrahedral form. Both these forms can exist in the same quite wide range of thermodynamic conditions; however, graphite can be transformed to diamond only at very high pressures, above 10 GPa. Evidence for a solid-to-solid phase transformation from diamond to a metallic state (Solid III), possibly cubic, is described at extreme high pressure (>100 GPa). The temperature-dependent material properties of carbon are shown in figure 5. The linear expansion coefficient increases with temperature whereas the modulus of elasticity fluctuates with temperature.

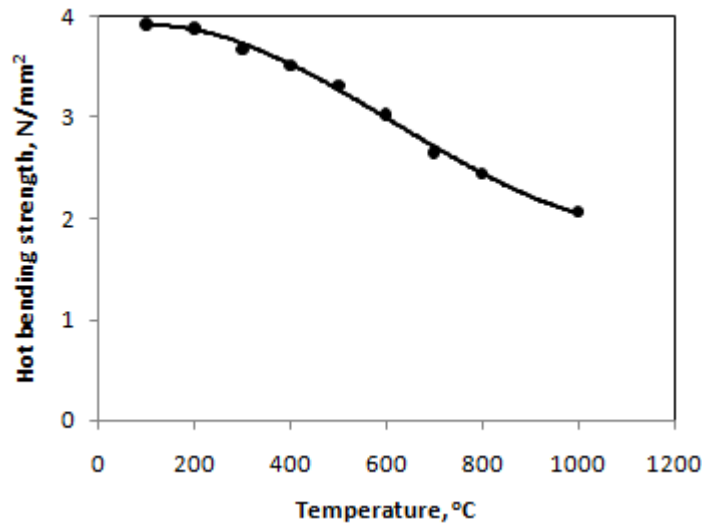


Figure 3. Effect of temperature on hot strength of ceramic shells.

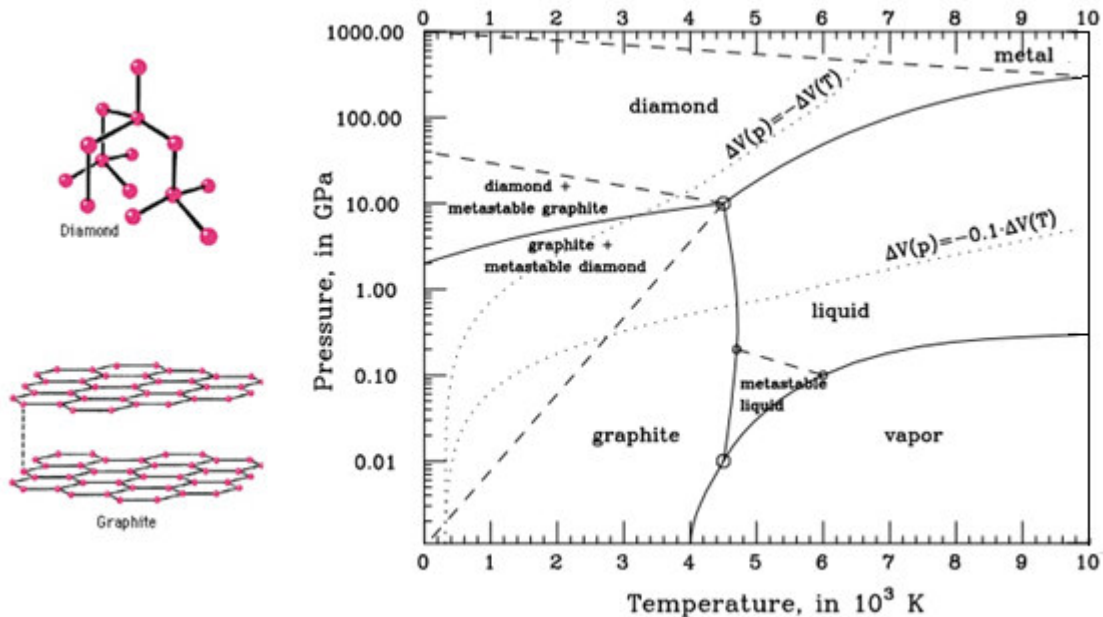


Figure 4. Phase diagram of carbon

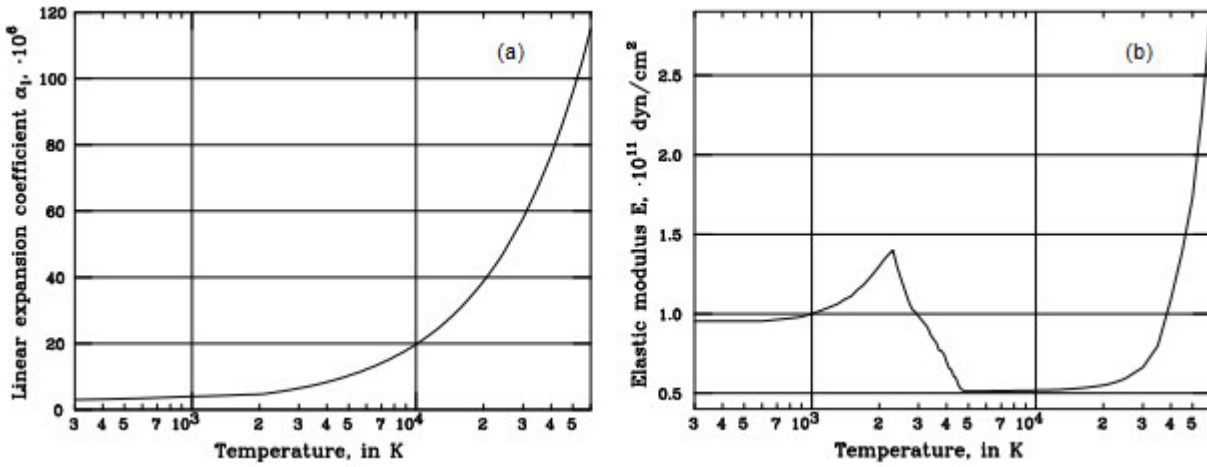


Figure 5. Temperature-dependent material properties of carbon (a) linear expansion coefficient and (b) elastic modulus.

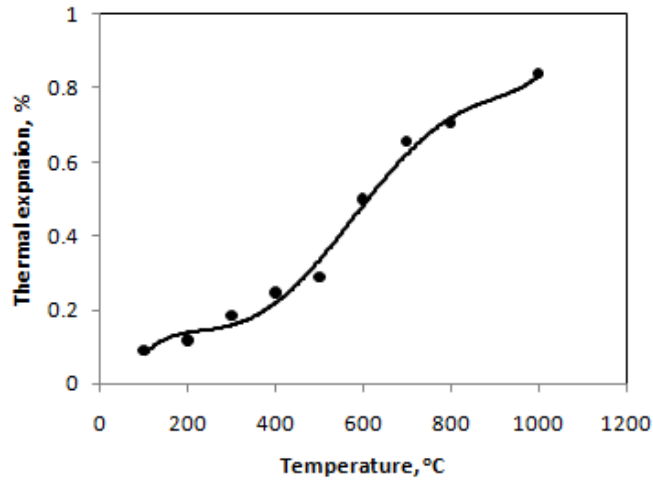


Figure 6. Effect of temperature on thermal expansion of shells.

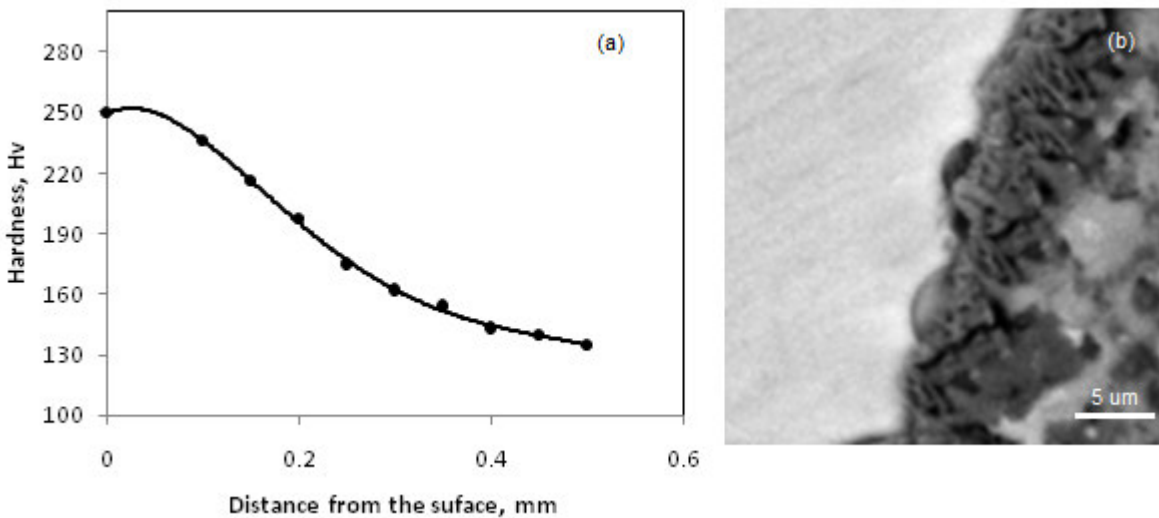


Figure 7. Metal-mould reaction (a) hardness variation and (b) formation of a phase

The thermal expansion curve for investment shells is illustrated in figure 6. The fluctuation is on account of  $\alpha$  to  $\beta$  phase transition of primary and back up sand used for sprinkling of shells. Figure 7a shows the hardness profile of a sample from 25mm thick TiAl alloy casting made in graphite investment shell mold. The hardness has a function of depth from the surface decrease with an increase in depth. This trend is indicative of presence of a hard alpha case layer beneath the surface of the casting. Formation of a thicker alpha (figure 7b) case in 25 mm thick casting is due to slower cooling rate experienced by the thicker casting and hence more time was available for titanium to react with the graphite.

#### 4. Conclusions

The hot bending strength graphite shells decreases with increasing temperature. The linear expansion coefficient of graphite shells increases with temperature. The presence of a hard alpha case layer is observed beneath the surface of the casting.

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