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RESEARCH ARTICLE

Thermo-mechanical Behaviour and Metal –to-Mould Reactions of Cristobalite Investment Shell Moulds to Cast Ti-6Al-4V Alloy

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Abstract

An investigation has been carried out to develop investment shell moulds from α- cristobalite and β- cristobalite as filler materials in the investment slurry. The shell characteristics in terms of hot bending strength and thermal shock were measured. The cracks were observed in the investment shell moulds prepared from the slurry containing α- cristobalite due to transformation of α- to β- cristobalite at 250^{o}C. Silicon was detected within the titanium substrate owing to the violent reaction between cristobalite and molten titanium.

1. Introduction:-

The materials used to build the investment shell mould, especially binders and refractories, play a vital role in the production of quality castings (Doskar and Gabriel, 1967). The investment casting process involves the production of castings using wax patterns. The coating of a wax assembly with refractory slurry is known as investing which gives rise to the name of investment casting process. The wax assembly is dipped into thin refractory slurry consisting of a liquid binder and a refractory powder. After draining, grains of refractory (stucco) are deposited onto the damp surface to produce the primary refractory coating. The use of stuccoing is to minimize drying stresses in the coatings by presenting a number of stress concentration centers. The second purpose of the stuccoing is to present a rough surface, thus facilitating a mechanical bond between the primary coating and the back up or secondary investment. When the primary coat has air-dried until the binder gels the assembly is systematically dipped into secondary slurry and stuccoed until the required thickness of shell is built up. The particle size of the stucco is increased as more coats are added to maintain maximum mould permeability and to provide bulk to the mould. Each coating is thoroughly hardened between coatings. Thus an investment casting mould consists of individual layers of fine refractory material and granular refractory material held together by a binder which has been set to a rigid gel.

After drying, the wax pattern material is removed in a steam autoclave, where the shells are subjected to steam at high temperature and pressure. Heat is transferred rapidly through the shell causing the wax to melt and drain away. The cavity left behind is an exact replica of the original pattern. The mould is then fired at a high temperature to remove any residual wax and to develop the bond strength of the binder. Metal can be poured into the mould whilst still hot or more usually the mould is allowed to cool and reheated to firing temperature before casting (Reddy et al., 1998; Satyanarayana et al., 1999; Reddy et al., 1999; Reddy et al., 2006). Melting and casting under vacuum is frequently used for high temperature alloys where avoidance of contamination by oxidation products is critical. The refractory filler materials used today to prepare the investment slurries are fused silica (Jebaraj and Reddy, 1998), zirconia (Karwiński et al., 2011), alumina (Reddy, 2001), yttria (Reddy, 1997), titania (Reddy and Sundararajan, 1997), graphite (Nirnajan and Reddy, 1998) and magnesia (Madhav and Reddy, 2000).

In the present work, cristobalite was used as refractory filler material to fabricate investment shell moulds for casting of Ti-6Al-4V alloy.

2. Materials and Methods:-

In the present work, the colloidal silica binder was used to fabricate the ceramic shells from cristobalite as reinforced filler material. The silica content in the colloidal silica binder was 30%. Two grades (primary and backup sands) of stuccoing sand were employed in the present investigation. Finer grade silica sand having AFS grain fineness number 120 was employed for primary coats. This is 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. Coarser grade sand having AFS grain fineness number 42 was employed for back up coats. This is river sand. The backup sand was employed to develop more thickness to the shell walls with minimum coats. After all coats, the shells were air dried for 24 hours. Two shells of each treatment were made. The Ti-alloy alloy was melted in an induction furnace under vacuum. The liquid alloy was gravity poured into the pre-heated investment shell moulds. The shell moulds were knocked off by hand hammer after solidification of the molten. The castings were cleaned with soft brush and visually inspected for pins and projections.

2.1 Strength of investment shell moulds

The dimensions of specimens are 25mm X 32mm X *t* mm, where *t* is the thickness of the shell mould. The three-point bending test (Doolman, 1966; Jackson, 1978) was conducted on the universal sand- strength testing machine with attached muffle furnace as shown in figure 1.

2.2 % Thermal Expansion of Investment Shell Moulds

It was measured in terms of %volume expansion of the investment shell moulds (Luneva, 1987; Vasin, and Lonzinger, 1987). 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:

$$\% \text{ thermal expansion} = \frac{V_2 - V_1}{V_1} \times 100 \quad (1)$$

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

2.3 Estimation of Metal-Mould Reaction

Vickers hardness was carried out to find the hardness of surface layers of the castings. Scanning electron microcopy was carried out to characterize the fine-scale topography and establish the microscopic mechanisms governing metal-mould reaction. The scanning was carried in IICT (Indian Institute of Chemical Technology - Hyderabad) S-3000N Toshiba shows Scanning Electron Microscope.

3. Results and Discussion:-

The cristobalite powder and its morphology are shown in figure 2. The cristobalite is a high temperature polymorph of silica having the same chemical formula as quartz SiO_2, but a distinct crystal structure. During the transition from a α- to a β-variant the atoms in the crystal lattice only get slightly displaced relative to each other, but they do not change places inside the crystal lattice. Cristobalite has a high temperature phase called beta cristobalite (figure 3b). The phase transformation cristobalite is

$$\alpha - \text{Cristobalite} \xleftrightarrow{270°\text{C}} \beta - \text{Cristoblite} \quad (2)$$

3.1 Hot bending strength of investment shell moulds

The effect of filler/binder ration on the bending strength of alumina investment shell moulds is shown in figure 4. The filler/binder ratio was 0.75 cc/ml. The hot bending strength of α-cristobalite was lower than that of β-cristobalite below 300°C. Above 300°C the hot bending strength of α-cristobalite was almost equal to that of β-cristobalite due to transition of α to β-cristobalite. Above 600°C the bending strength decreased owing to thermal shock (Reddy et al., 2001).

3.1 Thermal shock in investment shell moulds

The thermal expansion curve for investment shell moulds is demonstrated in figure 5. In case alpha cristobalite investment shell moulds, the thermal expansion was unstable and it increased very rapidly at 200°C. After transformation from α- to β-cristobalite, thermal expansion was stabilized. The thermal expansion curve of β-cristobalite investment shell moulds was lower than that of α-cristobalite. This was because β-cristobalite was stable at high temperatures. Due to thermal shock cracks were observed in the investment shell moulds produced from α-cristobalite filler material (figure 6).

3.3 Metal-mould reaction

Figure 7 reveals the microstructures of Ti-6Al-4V alloy castings produced from the investment shell moulds containing α-cristobalite (figure 7a) and β-cristobalite (figure 7b) filler material in the slurry. The microstructure was nearly same having α and β phases except small variation in the grain size. Fine grain structure was resulted in the Ti-6Al-4V alloy cast in β-cristobalite investment shell moulds. This might be due to difference in thermal conductivity of α- and β-cristobalites. The hardness as a function of distance from the metal-mould interface is shown in figure 8. The Vickers hardness was high at metal-mould interface due to reaction between mould material and Ti-6Al-4V alloy. The interfacial reaction layer was compared with Ti-6Al-4V alloy and mould material. Results of this comparison revealed that cristobalite were converted into a vitreous glassy silica phase to a depth of about 500 μ m. The silicon-to-oxygen ratio of the light phase was significantly higher than that of darker phase (figure 9). Silicon was detected only short distances within the titanium substrate. The violent reaction between cristobalite and molten titanium could have been due to contamination of cristobalite. This resulted in a lowering of the melting temperature of cristobalite and inducing the formation of metal slag and vitreous glassy silica with various stoichiometrics (McDeavitt et al., 2002).

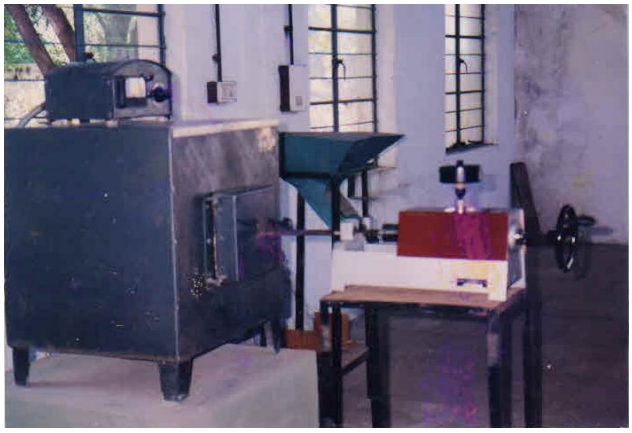

Figure 1: Hot bending strength test of investment shells.

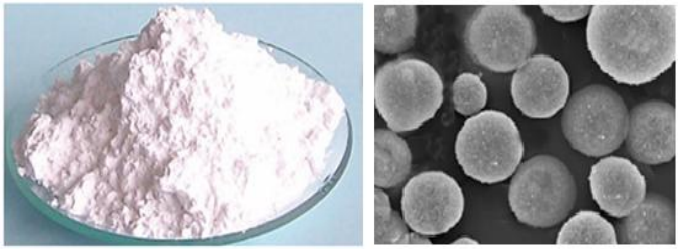

Figure 2: cristobalite: (a) powder and (b) morphology of particles.

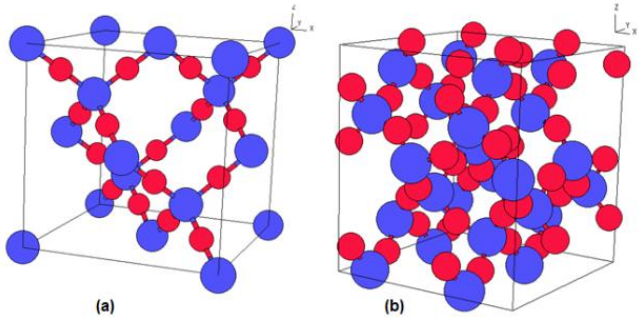

Figure 3: Crystal structures of cristobalite

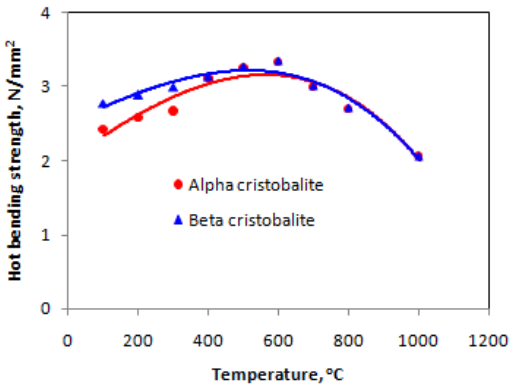

Figure 4: Effect of filler/binder ratio on bending strength of investment shell moulds.

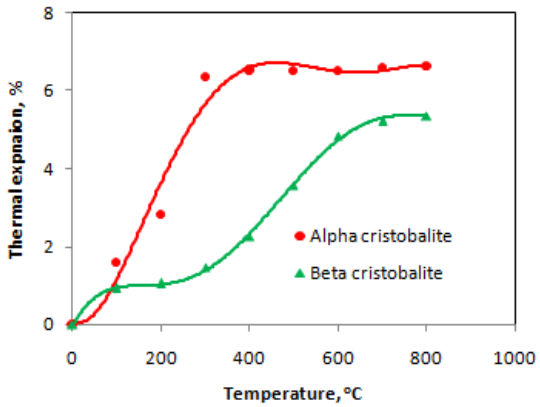

Figure 5: Effect of temperature on thermal expansion of shells.

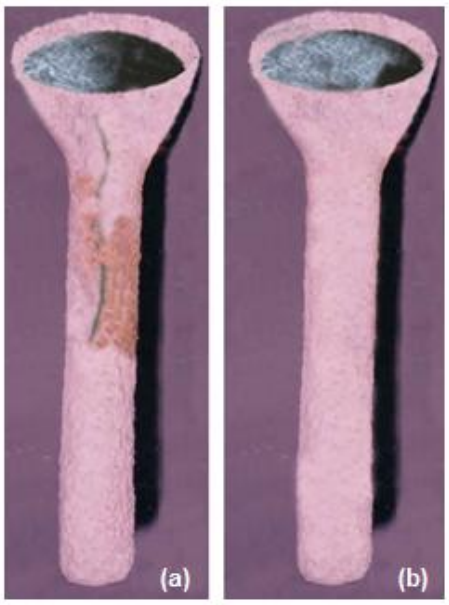

Figure 6: Thermal shock in the investment shell moulds made of (a) α-cristobalite (b) β-cristobalite filler material.

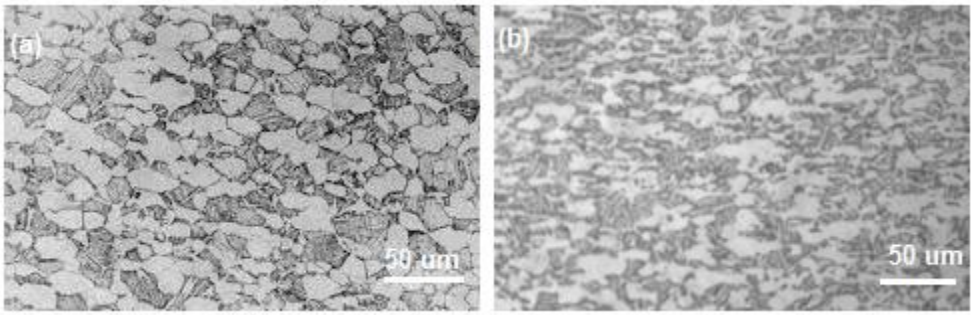

Figure 7: Microstructure of as- Ti-6Al-4V alloys in the investment shell moulds made of (a) α-cristobalite (b) β-cristobalite.

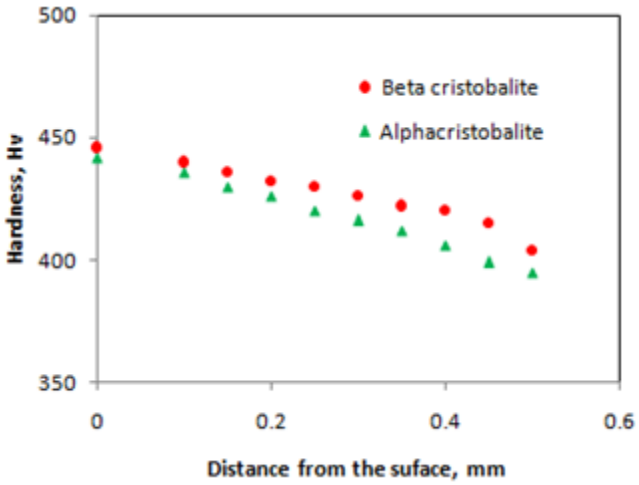

Figure 8: Hardness variation at metal-mould interface.

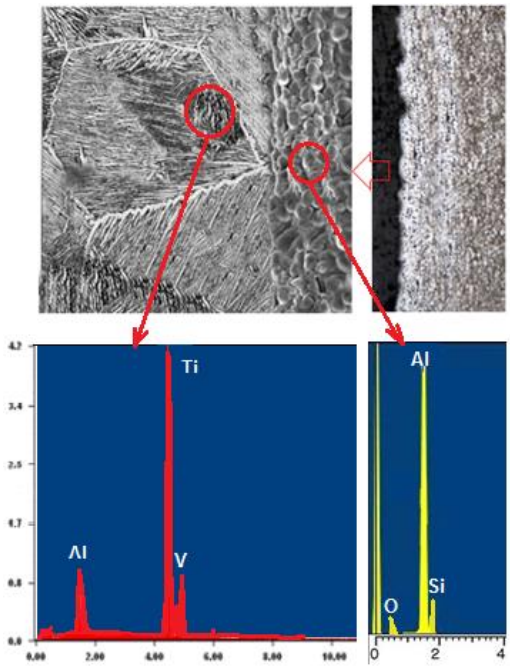

Figure 9: Metal-mould reaction.

4. Conclusions:-

The phase transition α- → β-cristobalite occurs at 250°. The cracks have been observed in the investment shell moulds made of α-cristobalite after Ti-6Al-4V alloy pouring. Silicon has been detected at the mould-metal interface.

5. References:-

Doolman, J. (1966): Standardization of methods of determining permeability and strength of ceramic shells. Foundry trade J., 121:724.

Doskar, J., Gabriel, J. (1967): How dip-coat materials affect ceramic investment shells –Part I. Foundry., 95:146.

Jackson, J.D. (1978): Evaluation of mould systems at high temperatures. 26th Annual Meeting, Phoenix, A2, Investment Casting Institute.

Jebaraj, P. M., Reddy, A. C. (1998): Prediction of thermal shock of ceramic shells using fused silica as reinforcing filler at casting conditions. National Conference on Advances in Production Technology, Bangalore.

Karwiński, A., Leśniewski, W., Pysz, S., Wieliczko, P. (2011): The technology of precision casting of titanium alloys by centrifugal process. Archives of Foundry Eng., 1:73-80.

Luneva, N.A. (1987): Coefficient of thermal expansion of investment moulds. Sov. Cast. Technol., 1:36.

Madhav Reddy, S., Reddy, A.C (2000): Interfacial Reaction between Magnesium Alloy and Magnesia Ceramic Shell Mold. National Conference on Advanced Materials and Manufacturing Technologies, Hyderabad.

McDeavitt, S.M., Billings, G.W., Indacochea, J. E. (2002): High Temperature Interaction Behavior at Liquid Metal-Ceramic Interfaces. J. Mater. Eng. and Perform., 11:382-404.

Nirnajan, H. B., Reddy, A. C. (1998): Investment shell moulds using graphite filler to prevent dimensional instability and metal-mould reaction of Ti-alloy castings. National Conference on Advances in Production Technology, Bangalore.

Reddy, A. C. (1997): Characterization of ceramic shells fabricated using yttria as reinforcing filler. National Conference on Advanced Materials and Manufacturing Technologies, Hyderabad.

Reddy, A. C. (2001): Development of Alumina Investment Shell Molds to Cast 7075 Al-Alloy. National Conference on Advances in Manufacturing Technologies (AMT-2001), 102-105.

Reddy, A. C., Murti, V.S.R., Sundararajan, S. (1998): Development of a ceramic moulding process from coal flyash for investment casting. 18th AIMTDR Conference, Kharagpur.

Reddy, A. C., Murti, V.S.R., Sundararajan, S. (1999): Control factor design of investment shell mould from coal flyash by Taguchi method. Indian Foundry J., 45:3-98.

Reddy, A. C., Murti, V.S.R., Sundararajan, S. (2001): Bonding mechanism in the coal-flyash ceramic shells. Indian Foundry J., 47:21-25.

Reddy, A. C., Murti, V.S.R., Sundararajan, S. (2006): Characterization of dip-coating slurries from coal-flyash for investment vesting process. Foundry Magazine, 18:51-54.

Reddy, A. C., Sundararajan, S. (1997): Characterization of ceramic shells using rutile (titania) as reinforcing filler at casting temperature. National Conference on Advanced Materials and Manufacturing Technologies, Hyderabad.

Rosenholtz, J.L., Smith, D.T. (1941): Linear thermal expansion and inversions of quartz. var. rock crystal, American Mineralogist, 26:103-109.

Satyanarayana, V.V., Reddy, A. C. Sundararajan, S. (1999): Reduction of Casting Porosity in the Lost-wax process choosing right coating materials by response surface criteria. CEMILAC Conference, Ministry of Defence, India.

Vasin, Y.P., Lonzinger, V.A. (1987): Calculating the thermal durability of investment shell moulds. Soviet Castings technology, 2:.47.