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Strength of Sillimanite Sand Reinforced Porcelain Subjected to Thermal Shock

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Abstract

An attempt has been made to eliminate quartz and gradually replace felspar by sillimanite sand to improve the thermomechanical properties of porcelains. It has been observed that the quenching temperature difference (ΔT) required to initiate thermal stress fracture in the porcelain increased greatly, when compared to classical compositions, with gradual replacement of felspar by sillimanite sand. Similar behaviour has also been observed in linear thermal expansion measurements. It was concluded that improvement in thermal shock resistance of the material was due to the absence of quartz and the presence of sillimanite — a volume-stable mineral — in addition to the decreased amount of glassy phase.

1 Introduction

Both the mineralogical composition and the microstructure influence the thermal shock resistance vis-à-vis thermal expansion of porcelains. The presence of glass and mullite content are the main sources of strength in triaxial compositions, the elastic modulus of the body increasing with the increase in glass content,[1] consequently decreasing the thermal shock resistance. Various attempts to increase the thermal shock resistance of triaxial compositions have been attempted by the incorporation of newer materials in porcelain composition inadvertently decreasing the glass content. Maiti[2] observed a 50% increase in thermal shock resistance in porcelain compositions by replacing quartz and felspar by sillimanite and cordierite glass-ceramics.

In our continuing effort to produce good quality porcelains from waste materials, we have earlier reported[3] the development of chemical porcelains from clay, felspar and sillimanite beach sand. Since these materials have also a great potential for use as ovenware ceramics, thermal shock resistance studies were also essential.

In the present investigation the thermal shock resistance of a new variety of hard porcelains was studied by single water quenching method. Theoretical results were verified experimentally.

2 Experimental Procedure

2.1 Material

Raw materials used in the present investigation were Amrapali china clay (North Gujarat), potash felspar (Jaipur) and beach sand sillimanite, a waste product obtained after separation of rare earths and other minerals from beach sand available in Kerala. A mix consisting of china clay 40%, china clay grog 20%, felspar 30% and sillimanite sand 10% was selected as the starting composition.

Felspar in the starting composition was progressively replaced by sillimanite sand. Batch compositions of the mixes are given in Table 1.

2.2 Specimen preparation

Required batch mixes were wet milled in porcelain pots with porcelain grinding media for 20 h to attain uniform particle size and required homogenization. The mixed slurry was discharged, passed through a magnetic channel and partially dried in plaster of paris moulds to retain the plasticity of the clay. The mass was then kneaded and pugged thoroughly with aging in a moist atmosphere for 24 h. The resultant aged mixes were extruded in the form of cylindrical rods 10 mm in diameter and 80 mm in length by a vacuum extruder. Dried specimens were fired at their respective maturing temperatures between 1200 and 1350°C.

Table 1. Porcelain compositions used (wt%) in thermal shock tests

Raw materials	*Body mixes*				
	1K	*2K*	*3K*	*4K*	*5K*
China clay	40	40	40	40	40
Calcined clay	20	20	20	20	20
Sillimanite sand	10	15	20	25	30
Potash felspar	30	25	20	15	10

2.3 Thermal expansion

Cylindrical specimens (4 mm diameter × 10 mm length) were prepared and fired separately. The linear thermal expansion was measured using a Netzsch 804 dilatometer at a heating rate of 10°C/min. Experiments were conducted up to 1000°C and results expressed in terms of percentage expansion and linear thermal expansion coefficient.

2.4 Thermal shock testing

Thermal shock measurements were carried out on a batch of at least 10 samples from each composition. Samples were heated at temperatures between 130 and 730°C in an electric furnace with programmable controller at the respective temperatures with a soaking of 30 min to attain uniformity in temperature. Heating rate maintained for all the tests was 50°C/h. Upon completion of soaking period samples were dropped into flowing distilled water (temperature 30°C). Severity of thermal shock was progressively increased by raising the temperature of the furnace. Specimens were then oven dried and the strength measured in a four-point bending fixture in an Instron 1185.

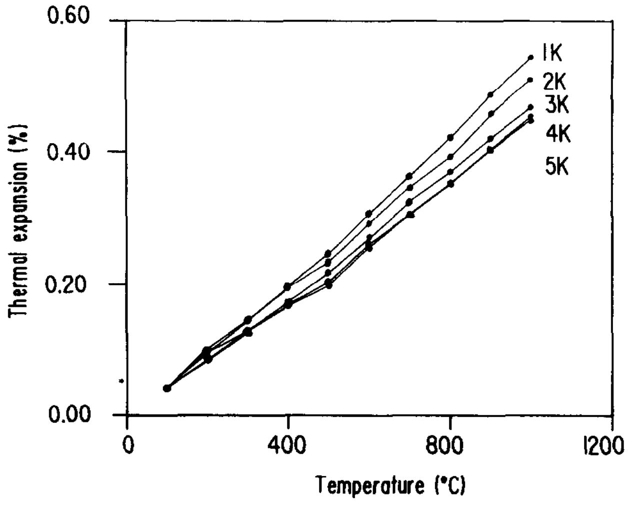

Fig. 1. Linear thermal expansion of different batches as a function of temperature.

3 Results and Discussion

As seen from Fig. 1, with gradual replacement of felspar by sillimanite sand the percent linear thermal expansion decreased.

The strength behaviour of the various porcelain compositions as a function of quenching tempera-

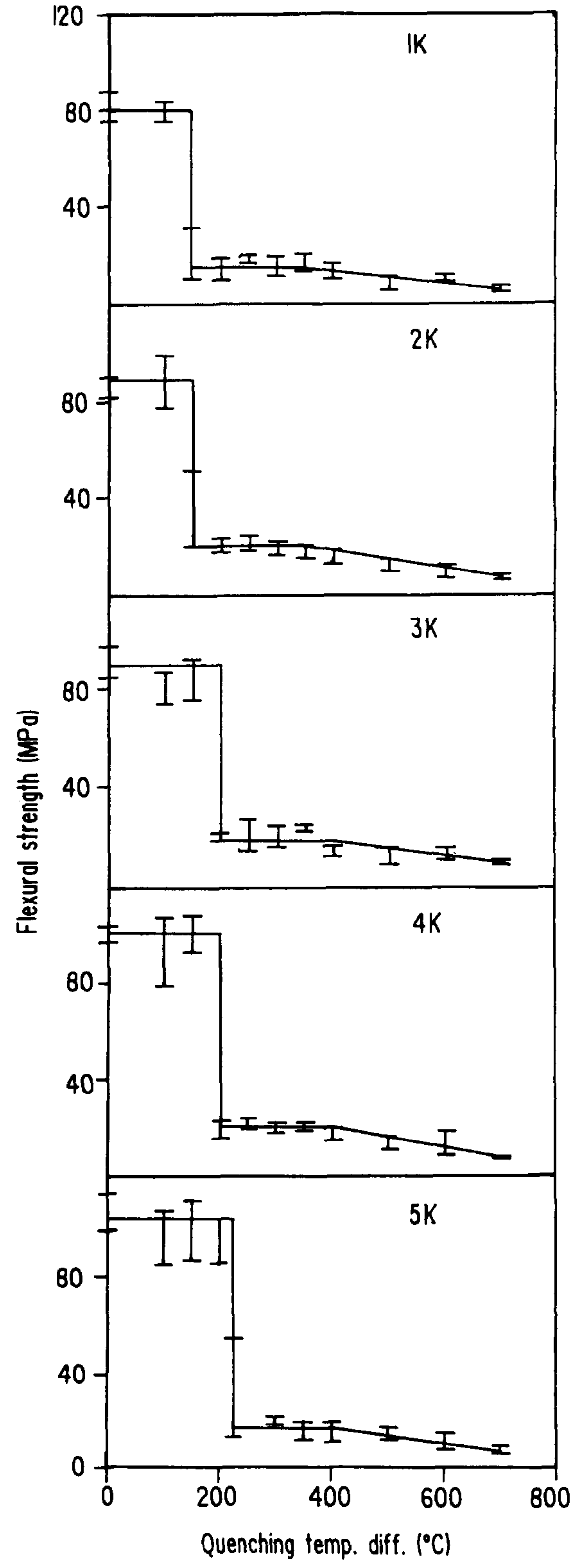

Fig. 2. Strength as a function of quenching temperature difference for porcelains of different compositions. (Error bars denote standard deviation).

ture difference is shown in Fig. 2. The observed data agreed in general with the expected theoretical behaviour as postulated by Hasselman.[4] A minimum temperature difference (ΔT_c) is required to initiate fracture. At the critical quenching temperature difference (ΔT_c) fracture is initiated and due to the kinetic behaviour of crack propagation the crack length instantaneously changes to a new value accompanied by a sharp discontinuous decrease in strength value. Gradual decrease in strength at higher quenching temperatures was due to quasi-static crack propagation.[4] The critical temperature difference required to nucleate fracture can be estimated by the approach of Glenny and Royston.[5] In general, the maximum thermal stress (σ_{max}) in a transient thermal shock test is:

$$\sigma_{max} = B\frac{\alpha E}{(1-\nu)}\Delta T \qquad (1)$$

where α is the coefficient of thermal expansion, E Young's modulus, ν Poisson's ratio, ΔT the quenching temperature difference and B a function of bh/k, where b is the rod radius, h the heat transfer coefficient and k the thermal conductivity. By equating σ_{max} with the bend strength, ΔT_c required to initiate fracture can be calculated. Both the estimated and observed values of ΔT_c have been compared in Table 2. Although the results agree qualitatively, quantitative agreement is lacking, since according to Hasselman[6] many uncertainties still exist in the prediction of thermal-stress fracture nucleation; much information on strain rate, specimen size, stress distribution and environmental effects on the strength is still required.

The effect of sillimanite sand addition on the critical quenching temperature difference (ΔT_c) is illustrated in Fig. 3. Both the estimated and observed values of ΔT_c have been plotted. The increase in ΔT_c with increase in sillimanite sand content can be explained by the avoidance of thermal stress fracture initiation required in materials with high values of strength and Young's modulus combined with low values of thermal expansion.

Table 2. Critical quenching temperature difference required to initiate fracture in porcelain rods

Sample No.	ΔT_c	
	Estimated	*Observed*
1K	97·30	100–150
2K	104·05	100–150
3K	117·86	150–200
4K	129·84	150–200
5K	137·73	200–225

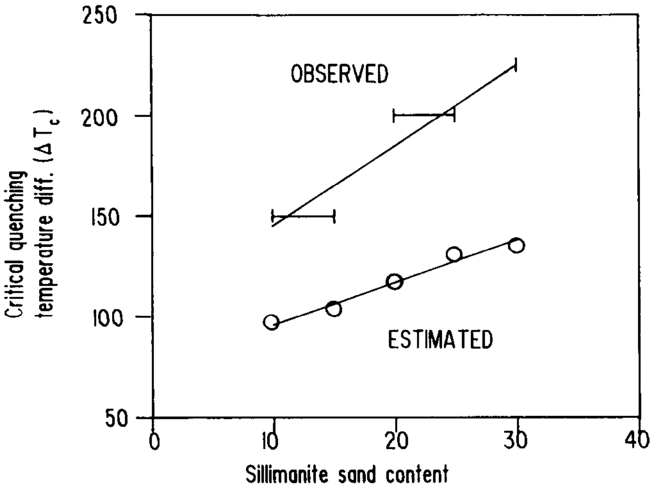

Fig. 3. Effect of sillimanite sand on the estimated and observed critical quenching temperature difference in porcelain compositions.

Based on the derivations of Davidge and Tappin,[7] for conditions of rapid heat transfer, the thermal stress resistance parameter (R) can be defined as

$$R = \alpha_b(1-\nu)/3E\alpha \qquad (2)$$

when α_b is the measured strength of the ceramic. Figure 4 shows the plot of ΔT_c versus the thermal stress resistance parameter. The thermal stress resistance parameter thus gave a good order of merit for behaviour of the present materials under water quenching.

The effect of body composition on thermal stress resistance parameter (R) has been illustrated in Fig. 5. With increase in the sillimanite sand content replacing felspar, resistance of the material to thermal shock increases. An important variable to be considered here is the coefficient of linear thermal expansion (Fig. 1).

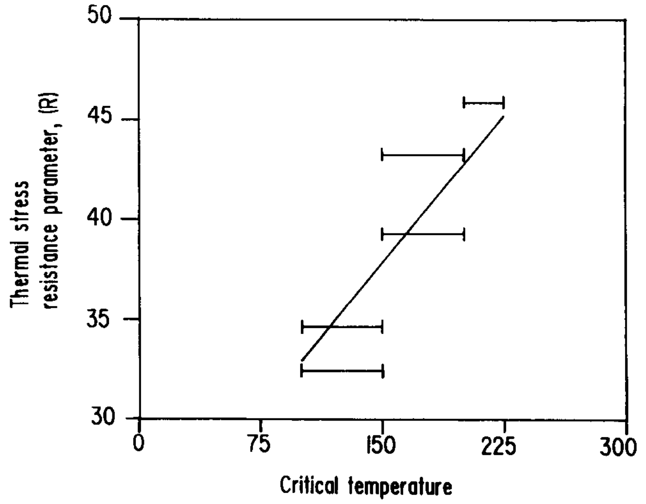

Fig. 4. Correlation between thermal stress resistance parameter and critical quenching temperature difference in porcelains.

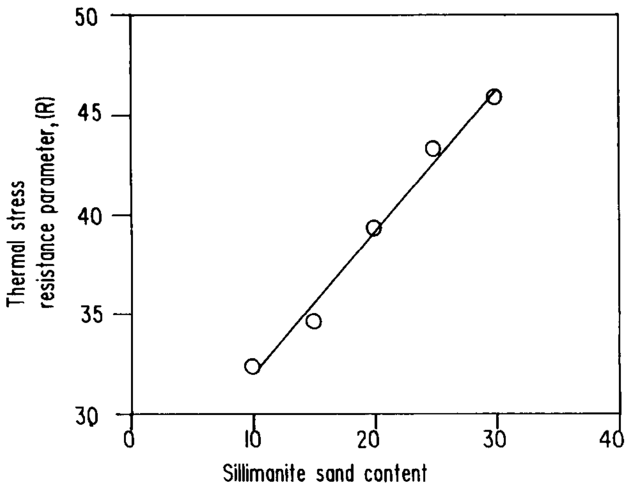

Fig. 5. Correlation between thermal stress resistance parameter and sillimanite sand content.

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