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Determination of the Firing Temperature of Ancient Ceramics by Measurement of Thermal Expansion

THE thermal expansion method for determining firing temperatures[1-3] is based on the assumption that, when clays are fired, shrinkage occurs as a result of various sintering processes such as vitrification. Consequently when a clay ceramic is heated up from room temperature (see Fig. 1) it typically exhibits a reversible expansion, characteristic of its mineralogical composition, until temperatures comparable with the original firing temperature are reached. With continued increase in temperature the ceramic begins to contract because superimposed on the reversible expansion there is an irreversible shrinkage associated with resumption of sintering (that is, the firing of the ceramic is being continued beyond the point reached during the original firing). The temperature (T_a) at which a net shrinkage is first observed should therefore provide an indication of the original firing temperature (T_e) of the ceramic.

Firing temperature determinations were undertaken on a selection of ceramics with a wide range of provenance and age (Table 1). Specimens ($2{\cdot}5 \times 1{\cdot}0 \times 1{\cdot}0$ cm) were cut from the pottery sherds and the shrinkage temperature, T_a, was measured using extension rod dilatometers[3,4]. The specimen was then refired for 1 h at temperature, T_e', and the new shrinkage temperature, T_a', was measured.

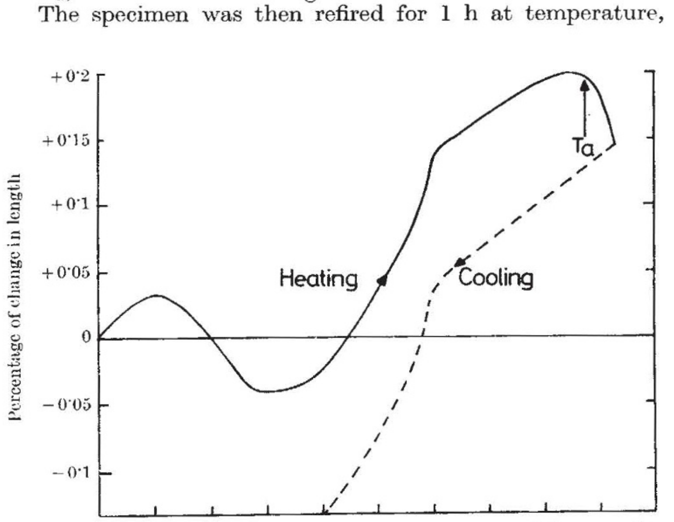

Fig. 1. Thermal expansion curves during heating and cooling for a typical ancient ceramic specimen (Pottersbury ware).

Table 1. FIRING TEMPERATURE OF ANCIENT CERAMICS

Provenance	Archaeological data Period/age	Type	Firing temperature (T_e °C)
Turkey	*c.* 5000 BC	—	750– 820
Iraq	*c.* 4500 BC	Halaf ware	970–1,050†
Iraq	*c.* 3500 BC	'Ubaid ware	1,140–1,180
Cyprus	*c.* 3000 BC	—	500– 700
Cyprus	*c.* 1300 BC	Mycenaean ware	940–1,000†
Cyprus	*c.* 1300 BC	Mycenaean copy	1,030–1,070†
Turkey	*c.* 500 BC	Greek Attic ware	1,000–1,100
Nigeria	—	Clay figurine	< 500
China	*c.* 1100 AD	Porcelain	1,070–1,140*
China	*c.* 1100 AD	Celadon	1,070–1,190*
China	*c.* 1700 AD	Porcelain	960–1,050*
England	Iron Age	Calcite gritted ware	< 800
England	Roman	Black burnished ware	500– 700
England	Roman	Grey ware	900– 960†
England	Roman	Colour coated ware	910– 980
England	Roman	Mortarium	930– 990
England	Roman	Samian ware	1,100–1,150
England	Saxon	—	500– 700
England	Saxon	Thetford ware	920– 960†
England	Mediaeval	Laverstock ware	750– 820
England	Mediaeval	Cowick ware	940– 990†
England	*c.* 1650 AD	Pottersbury ware	910– 950

* Presence of low viscosity liquid phase—T_e possibly too low.
† Bloating—T_e possibly too high.

The values obtained for T_a ranged from 620°–1,230° C. When T_a was less than 700° C, the thermal expansion data provided no precise information on the firing temperature and it was only possible to suggest that T_e was either less than 500° C or in the 500–700° C range, depending on whether or not hydrated clay minerals were present in the ceramics[5]. Similarly when the ceramic contained calcite, T_e was probably less than 800° C; the value for T_a being invalid because this mineral produced a complex pattern of expansion and contraction. For the remainder of the ceramics, T_e was calculated using the relationship

$$(T_e - T_a) = (T_e' - T_a')$$

Measurements on clay specimens, prefired at known temperatures, indicated that this relationship was valid for a wide range of firing temperatures provided vitrification occurred during the original firing and T_e' was selected such that $(T_e' - T_e)$ equalled approximately 20–30° C. Even in these circumstances, however, the value obtained for T_e may be too high as a result of bloating caused by the expansion of gases trapped in the liquid phase of the clay body. Alternatively T_e may be too low because shrinkage, resulting from the pressure exerted on the specimen by the dilatometer components, can occur when the viscosity of the liquid phase decreases at high temperatures.

The values estimated for T_e (Table 1) show that firing temperatures ranging from 500° 1,200° C were used in the manufacture of ancient ceramics and that low or high firing temperatures were not confined to particular periods or parts of the world. The data provide valuable information on the performance of ancient pottery kilns and on the technological capability of the potters. A knowledge of the firing temperature can also be valuable in other scientific investigations of ancient ceramics and kilns such as thermoluminescent and magnetic dating.

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