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Journal of the European Ceramic Society 35 (2015) 831–843

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The influence of microstructure and texture on the mechanical properties of rock tempered archaeological ceramics

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Received 9 May 2014; received in revised form 9 September 2014; accepted 16 September 2014
Available online 11 October 2014

Abstract

The influence of tempering and firing practices on the fracture strength and fracture energy of traditional pottery is presented, focusing on the mechanical behaviour of low-calcareous ceramics and how it compares to that of comparable calcareous ceramics. Material tests on experimental briquettes show that the measured increase in fracture strength upon firing is linked to the degree of vitrification in the ceramic matrix and to the development of porosity. The addition of aplastic inclusions reduces fracture strength, with platy temper affecting strength levels to a lesser degree. In earthenware, high fracture energy can normally be obtained by adding high amounts of aplastic inclusions as temper. While the fracture energy of granite-tempered ceramics remains approximately constant at high firing temperatures, for phyllite-tempered materials maximum values are found at intermediate temperatures. Regarding archaeological ceramics, the data presented here are anticipated to contribute to our understanding of technological choices in their manufacture.

Keywords: Mechanical properties; Strength; Fracture energy; Inclusions; Archaeological ceramics

1. Introduction

The study of the mechanical properties of traditional ceramics has received increasing attention in recent years. The influence of manufacturing parameters such as firing temperature or tempering practices on the mechanical properties of earthenware has been studied with the objective, on the one hand, of improving contemporary ceramic materials, mainly in the brick and tile industry[1–3] and on the other, to assess technological choices in archaeological ceramics.[4] As far as archaeological ceramics are concerned, the need to place such assessments into context and to take into account the multitude of other factors that influence technological choice has been emphasised in various reports (e.g. [5]; epilogue of Ref. [6]). An understanding of mechanical performance, while not per se explaining technological variation in the past, provides nevertheless a valuable baseline for the consideration of the overall reasons for technological choices observed in archaeological ceramics.

Pottery is exposed to various mechanical stresses during manufacture and use-life and is normally expected to remain usable without structural damage or loss of functionality. The nature and the magnitude of these external stresses depend to a large extent on the actual use of the vessel. Regarding archaeological ceramics, vessels which are expected to withstand mechanical stresses include amphorae, which need to be able to bear the load of overlying vessel layers when stacked during transportation, while all vessels used as a container should withstand the pressure exerted by their contents without fracture. For such sustained stresses it is the fracture strength as well as fracture energy of the material which determine the vessel's survival.

Fracture strength and fracture energy of traditional as well as archaeological ceramics are known to be dependent on variables such as the amount and type of temper and firing temperature as has been clearly demonstrated in the review of Tite et al.[4] A series of studies (e.g. [6–9]) have contributed to our knowledge of the effect of technological choices on the performance of archaeological ceramics, especially regarding the influence

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http://dx.doi.org/10.1016/j.jeurceramsoc.2014.09.025

of the volume fraction and grain size of temper on mechanical properties. In addition, the influence of temper type and shape have been demonstrated to be of importance in the performance of clay based ceramics.[8,10–12] The overall picture is, however, complicated since the microstructure of the ceramic matrix itself also contributes to overall mechanical performance. Calcium-rich clays are known to undergo a different microstructural development during firing than calcium deficient clays[13,14] and different mechanical behaviour is therefore expected in these two cases. Both calcareous and low-calcareous clays have been used in the past. In many instances calcareous and low-calcareous clays were used for manufacturing vessel types that differed in intended function. Differentiation in the use of clays according to their calcium content is also documented ethnographically: so, for example, calcareous clays are used widely in the production of water jars, while cooking vessels are often preferentially made of low-calcareous clays.[15] Beyond synchronic variation, there are also diachronic shifts in clay preferences, such as the widespread change to calcareous clays at the start of the Middle Bronze Age in the Aegean, which largely replaced earlier low-calcareous materials.

It is clear, therefore, that a comprehensive assessment of the mechanical performance of tempered clay-based ceramics which takes into account the influence of *clay-type* – i.e. low-calcareous vs. calcareous base clays – has much to contribute to discussions of material affordance and suitability for archaeological and traditional ceramics. It is with this in mind that a range of briquettes was manufactured from both a low-calcareous and a calcareous base clay to be tested for their mechanical properties. Granite and phyllite, which are encountered frequently in Aegean Bronze Age ceramics, were chosen as temper materials. Discussion in the present article, while focusing on the mechanical behaviour of the low-calcareous clay, also elucidates how it compares to comparative calcareous ceramics, which have been presented elsewhere.[6,12] The influence of manufacturing parameters on fracture strength and fracture energy of traditional ceramics is discussed based on the microstructural and textural changes they induce in the ceramic material. Besides furthering our understanding of the mechanical behaviour of traditional clay-based ceramics, it is anticipated that this work, along with the existing literature, will provide a baseline for the discussion of the relationships connecting manufacture, function and affordances of archaeological ceramics.

2. Experimental procedure

In order to investigate the influence of tempering on the mechanical properties of clay-based ceramics, a series of experimental briquettes was manufactured, assessing the influence of amount and type of temper on their mechanical properties over a range of firing temperatures.

2.1. Materials and processing

Test specimens were fabricated with a low-calcareous (<0.5% CaO) clay from Kalami (Crete, Greece). This clay has been used in a previous study of thermal properties and its chemical and mineralogical composition is described elsewhere.[16] The calcareous clay used in the comparative experiments was obtained from Pikermi (Attica, Greece) and contains c. 14% CaO.[12] A fraction with a particle size of <30 μm was separated from the raw clay and mixed with angular granite grains from the island of Naxos (Greece) and platy phyllite from the Northeast Peloponnese (Greece), respectively. Both materials were crushed and sieved to pass through a 1 mm mesh size, discarding the fraction which would pass through a 0.5 mm mesh size (in the case of the platy phyllite, the aspect ratio of the temper particles was approximately 1:5–1:10).

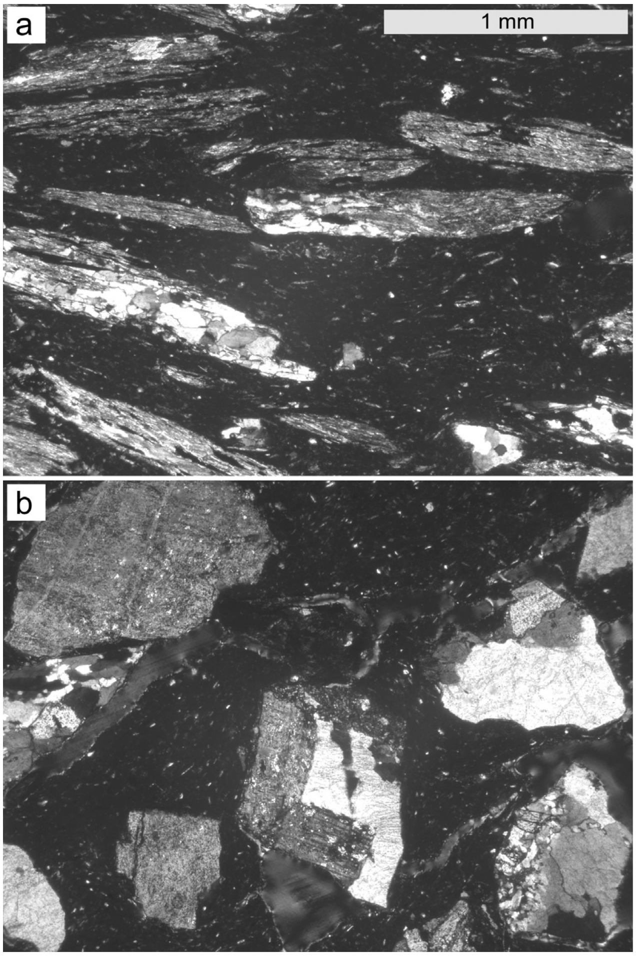

Fig. 1. Thin section micrographs of (a) phyllite and (b) granite temper. Crossed polars, 50×.

Phyllites are fine-grained metamorphic rocks derived from argillaceous sedimentary rocks. They have well developed cleavage surfaces, due to the parallel alignment of platy minerals, usually micas. X-ray diffraction measurements using a Siemens D500 diffractometer with Cu-K_α source confirmed quartz, muscovite, chlorite and traces of hematite in the sample taken and used as temper material. The phyllitic temper grains are dominated by layered micas, with some more quartz rich grains present as well (Fig. 1a).

Granite is a coarser grained, igneous rock composed principally of quartz and feldspars. Weathered granitic rock fragments were collected at an exposed igneous granodiorite–granite