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A study on the strength and thermal shock resistance of Egyptian shale-tempered pottery

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ABSTRACT

The characteristic shale-tempered pottery found in Egypt's Western Desert is often discussed for its potential strength properties and resistance to thermal shock. This paper reports on a recent experiment that tests these properties using replicate shale-tempered ceramic beams. The beams were thermally treated and flexure-tested on a three-point loading jig. The results indicate that shale in sufficient concentrations and size has an effect on vessel strength and thermal shock resistance, though the relationship is more complex than expected. Importantly, this study highlights the potential for integrating new methods of materials analysis into research on ancient Egyptian ceramics.

1. Introduction

Towards the end of the seventh millennium bce a new type of pottery emerged in Egypt's Western Desert characterised by thin walls, smoothed surfaces and a lack of decoration (Kuper, 1995) – features that distinguish it from the heavily-decorated 'wavy-line' wares that appeared widely throughout the region from the tenth millennium onwards (Close, 1995; Jesse, 2010). An important development in the new pottery tradition was the emergence of 'shale ware', a fairly loose term used to describe any number of fabrics that have shale as a key inclusion: this includes fine and coarse sand-and-shale fabrics, and shale-rich fabrics with very coarse particles (Eccleston, 2002: 62–4; Hope, 2002 *passim*; Riemer, 2011: 38–51, Warfe, in prep).

Gatto's (2012) recent survey of shale-tempered finds in Egypt demonstrates the broad spread of this pottery type throughout late prehistory. The earliest dated examples come from the central Western Desert (Fig. 1) where they appear in sixth millennium bce contexts, while later examples are found in the southern Western Desert (Nabta–Kiseiba area) and along the Nile Valley dated to the fifth and fourth millennia respectively (Gatto, 2012). As a natural inclusion in the local geology it is not unusual to find shale-tempered pottery across the region,[1] and as Eccleston (2002: 65) notes, this spread complicates attempts to identify a bed or zone of exploitation tapped by ancient potters.

Research on the early pottery from Dakhleh Oasis (Fig. 1) indicates that the coarser versions of the shale fabrics were becoming more common over time (Hope, 2002; Warfe, 2006, in prep). Here, as elsewhere, it is suggested that the presence of shale particles, especially the very coarse particles, was intended to confer strength and/or thermal shock resistance to the finished vessel (Ballet and Picon, 1990, 80; Friedman, 1994: 260, 632–3, 870; Hope, 2002: 40; Riemer, 2011: 58–9). There is good supporting evidence to argue this case. The environmental and archaeological records for the period c. 3500 indicate tougher living conditions in northeast Africa with the final onset of aridity (Kuper and Kröpelin, 2006), a point at which pottery vessels were becoming more common and showing signs of hasty manufacture (Hope, 2002; Warfe, in prep). The full extension of the argument is that more rigorous cooking activities were developed by desert groups to extract nutrients from foods or to render certain foods palatable – e.g. cooking splintered bones for marrow extraction (*sensu* McDonald, 2002: 118) – and this required more robust vessels to be made in greater numbers.

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[1] Shales appear widely throughout Egypt's Western Desert in geological formations that extend across the oases, along the edge of the Nile Valley, and down towards the Sudan (Said, 1962: 130–5).

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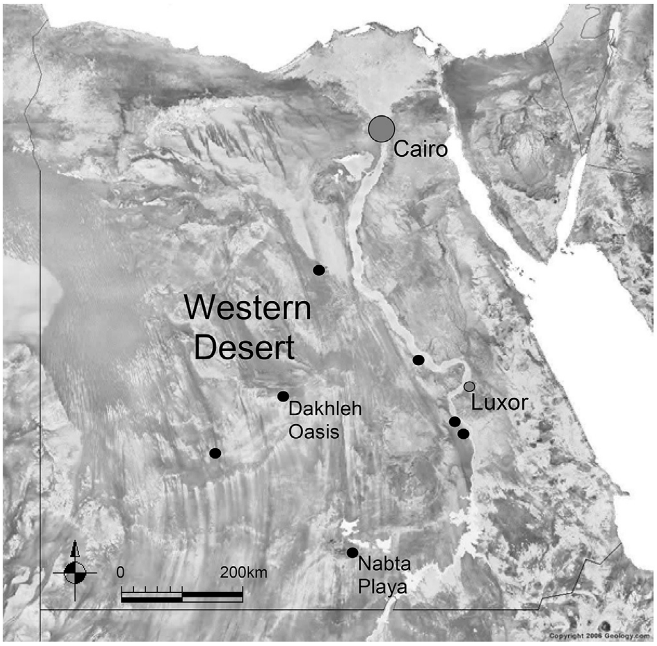

Fig. 1. Map of Egypt with sites (black dots) yielding shale-tempered pottery (following Gatto, 2012).

This study examines the strength and thermal shock qualities of shale-tempered pottery through experiment. This involved strength-testing ceramic beams constructed from clays consisting of various grades of shale, half of which were subjected to thermal shock treatment. The investigation draws on the history of strength-testing ancient ceramics and applies the same methods of thermal shocking and flexure testing, while the results are discussed critically in relation to the controlled setting. Importantly, this investigation highlights the need to expand research on Egyptian ceramics to look more closely at the role of pottery in consumption, especially in the early periods – a point of interest pre-echoed in the literature for some years (Friedman, 1994: 240–79; Nelson, 2002: 99). Sustained research in this area can produce far-reaching results for the discipline given the prevalence of ceramics in the archaeological record. While recent studies have approached the issue from the standpoint of the archaeological 'context' (e.g. Bader and Ownby, 2013; *passim*), a useful contribution will be to examine the pottery itself as an indicator of its role in Egyptian antiquity.

2. Testing ancient ceramics for strength and thermal properties

Research on the mechanical and thermal properties of ancient fabrics began, properly, with Anna Shepard's *Ceramics for the Archaeologist* (Skibo, 2013: 37; Tite, 2008: 216). Shepard (1965: 125–38) advocated an approach to ceramic analysis based on understanding the properties of the material by drawing on principles of the physical sciences. This approach gained purchase in the 1980s and 1990s with a number of experimental studies conducted to test the mechanical and thermal properties of ancient ceramics (Braun, 1983; Feathers, 1989; Feathers and Scott, 1989; Hoard et al., 1995; Kilikoglou et al., 1995, 1998; Mabry et al., 1988; Neupert, 1994; Skibo et al., 1989; Steponaitis, 1984). At their core, these studies were concerned with whether a pot is capable of retaining its contents, surviving impact, and surviving rapid temperature fluctuations: qualities typically phrased in terms of 'strength', 'toughness' and 'thermal shock resistance'.

In low-fired ceramics, strength equates with the vessel's ability to withstand sustained stress brought about by the contents placed in the vessel (Tite et al., 2001: 302). It is measured as '… the stress at the maximum [point] on the engineering stress–strain curve' (Callister, 2000: 125) indicating the point at which fracture has occurred. Importantly, cracks and flaws within the material act to concentrate stress, promoting failure. Because of this, strength is more an indicator of cracks and flaws than the sample's intrinsic properties (Kilikoglou et al., 1998: 278; Tite et al., 2001: 303). Toughness, by contrast, may be considered an intrinsic property of the ceramic body (Tite et al., 2001: 303–4). It is defined as '… the ability of a material to absorb energy up to fracture' (Callister, 2000: 130) and to dissipate energy beyond fracture until catastrophic failure. In low-fired ceramics this can be equated with the vessel's ability to withstand complete failure on impact – cracks are quickly arrested requiring additional load until final failure (Tite et al., 2001: 305). Materials with greater strength tend to produce an unstable displacement curve (Fig. 2), while those with greater toughness produce semi-stable and stable displacement curves (Fig. 2).

Thermal shock resistance relates to the vessel's ability to withstand sudden heating and cooling. Rapid temperature fluctuations can cause the interior and exterior surfaces to contract and/or expand differentially, thus weakening the material (Bronitsky, 1986: 249–50). The stress created through this process is sufficient to initiate cracks and flaws within the ceramic body. Microdamage can also arise through the behaviour of certain tempers – quartz, for instance, expands when heated and can be an additional cause of failure due to thermal activity (Tite et al., 2001: 313). In the ancient past, the obvious example in which a vessel is subject to thermal shock relates to cooking activities.

Strength, toughness and thermal shock resistance are dependent on a range of factors: clay constituents, temper and porosity, drying rate, wall thickness, wall curvature and firing temperature. Some general principles have been outlined in studies on modern industrial ceramics (Grimshaw, 1971; Kingery et al., 1976), while archaeologists tend to focus on temper type and concentration. Shepard (1965: 131) posited that 'In general, the greater the amount of temper, the weaker the body'. Although this still holds (Tite et al., 2001: 310, 321), the relationship between temper and vessel strength is complex and conditioned by the shape, size,

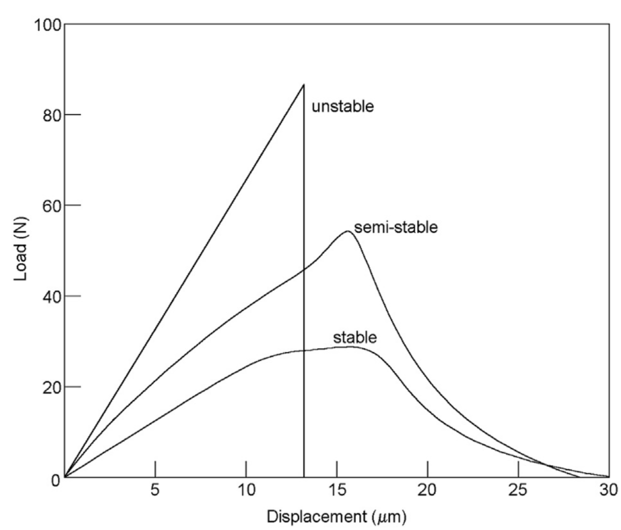

Fig. 2. Hypothetical displacement curves (adapted from Tite et al., 2001, Fig. 1).