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# Tempered strength: A controlled experiment assessing opportunity costs of adding temper to clay

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ABSTRACT

The addition of pottery additives (temper) provides both production-based benefits gained during the initial vessel formation phase, and performance-based benefits associated with post-firing vessel daily use. This paper presents the results of a controlled archaeological experiment designed to assess the opportunity *costs* associated with the addition of temper to clay during prehistoric pottery production sequences. Specifically, this study builds upon earlier research using material science methods to more broadly assess whether vessel strength is sacrificed by the addition of temper into the clay body. Standardized experimental ceramic test specimens, based directly upon petrographic analysis of archaeological samples from a regional context (South Central Ohio, USA) and produced using glacially-deposited illite-based clay, were subjected to mechanical strength tests using an Instron Series IX universal testing machine. The results demonstrate that there are indeed opportunity costs associated with temper addition: lost potential strength and reduced vessel use-life. Overall, untempered samples were significantly stronger than samples tempered with the most commonly used regional tempers—grit, limestone, and burnt shell—in terms of peak load and modulus of rupture. In other words, the results presented here suggest that prehistoric potters were losing the opportunity to create significantly stronger vessels in favor of the benefits that come with the addition of temper. Understanding of the existence, kind, and degree of opportunity costs that come with the addition of temper to clay emphasizes just how important the benefits of tempering must have been for the technology to be invented, experimented with, and ultimately so widely adopted.



## 1. Introduction

A fundamental research area for archaeologists is understanding by what means, and for which potential motivating factors, prehistoric technologies emerged and evolved (e.g. Bettinger et al., 2006; Buchanan and Hamilton, 2009; Buchanan et al., 2014; Cochrane, 2001, 2004, 2008; Cochrane and Lipo, 2010; Cochrane et al., 2013; Eerkens and Lipo, 2005, 2007; Eren et al., 2015, 2016a, 2016b; Fitzhugh, 2001; Hamilton and Buchanan, 2009; Henrich, 2004; Jordan, 2014; Jordan and Shennan, 2003; Kempe et al., 2012, 2014; Lycett, 2009, 2011, 2013, 2015a, 2015b, 2017; Lycett and von Cramon-Taubadel, 2015; Mesoudi, 2011; O'Brien et al., 2014, 2015, 2016a, 2016b; Schillinger et al., 2014a, 2014b, 2015, 2016, 2017). From an economic or efficiency standpoint, it can be predicted that behaviors which speed up production processes or more effectively make use of raw materials would be favored by selection (Bettinger et al., 2006; Fitzhugh, 2001). However, in some instances, specifically in multi-step manufacturing sequences, additional steps are added which can be labor-intensive. These additional steps increase production time, overall raw material cost, and total craftsperson energy expenditure—so why do them? The common logical assumption archaeologists make is that there must have been a functional benefit resulting from these additional production costs. As Bettinger et al. (2006:41) note, “It will never pay to invest in a more costly technology that yields a lower rate of procurement… Neither can it ever pay to invest in a cheaper, less productive technology if technological investment in the more costly and productive technology improves procurement at a higher rate.” In the study of ceramic technology, only in recent years have these functional benefits been started to be explicitly and quantitatively tested consistently via controlled experiment (Hoard et al., 1995; Feathers, 1989, 2006; Kilikoglou et al., 1995, 1998; West, 1992; Müller et al., 2010; Tite et al., 2001), although earlier examples exist (Bronitsky and Hamer, 1986; Rye, 1976;

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Shephard, 1985; Steponaitis, 1984).

The production of pottery is a multistep process and thus presents many opportunities in which efficiency can either be increased or decreased. For example, to produce a vessel, potters must go through the entire production sequence which involves sourcing the raw clay, processing and the refining clay to remove impurities, preparing and adding temper, shaping the vessel, drying the form, and firing the form, in addition to dealing with issues that occur during every day vessel use such as breakage and repair (Ali, 2015; Rice, 1987).

In pottery manufacturing sequence, one of these “additional steps” practiced by ancient potters involved the regular modification of the raw clay body either via dry sorting by hand or with water filtration (Hodges, 1989; Rice, 1987), followed by the addition of one or more tempers. The addition of temper can be thought of as a form of specialized knowledge that demonstrates prehistoric potters' ability to understand how temper can aid in vessel size and shape formation, improve drying, prevent warping, and eliminate blowouts during firing (Ali, 2015; Bronitsky and Hamer, 1986; Childs, 1989; Feathers, 1989, 2006; Feathers and Scott, 1989; Hoard et al., 1995; Kilikoglou et al., 1995, 1998; Müller et al., 2010; Rye, 1976; Skibo et al., 1989; Schiffer et al., 1994; West, 1992). In other words, pottery additives (i.e. tempers) provide both *production-based* benefits gained during the initial vessel formation phase, and *performance-based* benefits associated with post-firing vessel daily use. Even so, while several studies have conclusively demonstrated that temper does indeed provide benefits to post firing vessel performance, more experimental work is needed to tease apart whether *production-based* or *performance-based* functions were important factors motivating temper adoption, use, and subsequent change over time in specific regional contexts.

One question that has received less attention is whether there are *opportunity costs* to vessel performance when adding temper to clay. That is to say, are there performance-based benefits of *untempered* ceramics that are unavoidably lost when temper is introduced?

By definition, an opportunity cost refers to a benefit that a person could have received—but gave up—in order to take another course of action. Stated differently, an opportunity cost represents an alternative given up when a decision is made (Fitzhugh, 2001). If we apply this idea to past material culture, it follows that during the process of innovation, producers must weigh their options—if investing more time and effort into a given strategy—we can predict that the pay-off should outweigh the added cost in energy expenditure by producing a more durable or longer lasting product. In the context of prehistoric pottery production, it would be expected that potters would want to reduce effort while creating the most durable product.

Earlier studies have looked at temper function on vessel durability as measured via mechanical properties related to fired vessel strength and toughness. Much of this previous research emphasized the role of temper for prolonging vessel use-life (Bronitsky and Hamer, 1986; Hoard et al., 1995; Feathers, 1989, 2006; Kilikoglou et al., 1995, 1998; Müller et al., 2010; Rye, 1976; Shephard, 1985; Steponaitis, 1984; Tite et al., 2001) However, in two of these studies (West, 1992; Kilikoglou et al., 1995), the data suggest that temper may not be adding to the durability of the fired ceramic. In fact, their results show that temper addition may be creating a weaker vessel wall.

In a study by West (1992) various temper types were tested against one another, and also against an untempered control sample of clay. Using test samples created from commercially produced clay (Red Art Earthenware), West (1992) found via mechanical testing that the fracture strength of the untempered ceramic was stronger than that which used any form of temper at 20% density, including burnt shell, grog, diatomite, sand, quartz, mica, and wollastonite. Likewise, Kilikoglou et al. (1995, 1998) made pottery test samples from a calcareous clay commonly used to produce Aegean Bronze Age pottery, and evaluated the effects of quartz temper on the mechanical properties of the ceramic. Like West (1992), Kilikoglou's results suggested that test samples *sans* temper were stronger than those with it. *In toto*, West's (1992) and Kilikoglou et al.'s (1995, 1998) results point to the intriguing idea that clay without temper creates a stronger vessel more resistant to crack initiation relative to one made from clay with temper. In other words, it appears the addition of temper to clay does indeed come with a considerable opportunity cost related to initial fracture resistance.

Here, I build upon the work of West (1992) and Kilikoglou et al. (1995, 1998) to assess whether vessel strength is sacrificed via temper incorporation into clay. A controlled experiment (Eren et al., 2016a,b) was designed to address the possibility of an opportunity cost by assessing the mechanical properties of an un-tempered clay body. The null hypothesis states that, if there is in fact an opportunity cost to adding temper to clay, then we can predict that tempered ceramic test samples will exhibit weaker mechanical properties than untempered samples. However, the alternative hypothesis states that if there is not an opportunity cost to temper incorporation into clay, we can predict that there will be no difference between the mechanical properties of tempered versus untempered samples, or that tempered samples will be stronger.

While maintaining overall experimental consistency with these previous studies via the use of standardized test samples, mechanical testing instrumentation from the engineering sciences, among other items, this present study makes several strategic alterations to test design, variables, analysis, and levels of internal and external validity (Mesoudi, 2011; Lycett and Eren, 2013; Outram, 2008; Eren et al., 2016a). While these details are discussed below (see section 2. Materials and Methods), three broad changes are worth mentioning here. First, the present study uses experimental test specimens based upon a particular prehistoric context, and from a different geographic region, than those discussed in West (1992) and Kilikoglou et al. (1995, 1998), namely the Late Woodland/Prehistoric period (A.D. 500–1600) of South Central Ohio, U.S.A. This geo-temporal focus required the use of a glacially deposited illite-based clay widely abundant in South Central Ohio (directly procured by the author), and three temper types commonly used in the region—grit, limestone, and burnt shell. This first experimental design change is inherently tied to the second design change, which involves the “quality” of clay. West's (1992) and Kilikoglou et al.'s (1995, 1998) results were based on the use of high quality clays, such as commercially produced clay (West, 1992) or naturally occurring calcareous clay (Kilikoglou et al., 1995, 1998). This exclusive use of refined clays in previous ceramic strength tests raises the question as to whether temper weakens *all* clay bodies regardless of quality, or simply high quality ones. The lower quality glacially deposited illite-based clay used in the present study addresses this question. Finally, unlike previous studies on experimental ceramic strength, the present study makes use of inferential statistical analysis to assess its quantitative data, rather than make visual assessments based solely on graphical representation of sample averages.

## 2. Materials and methods

The following research expands upon earlier experimental work by using petrographic thin section analysis to identify volumetric density of multiple temper types from specific temporal-spatial contexts. The goal was to use the density data to construct the