Journal of Archaeological Science: Reports xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Replicating surface texture: Preliminary testing of molding compound accuracy for surface measurements

Danielle A. Macdonald[a,*], Adrian A. Evans[b], Robert Harman[b]

[a] Department of Anthropology, The University of Tulsa, 800 S. Tucker Drive, Tulsa, OK 74104, United States
[b] School of Archaeological and Forensic Sciences, University of Bradford, Bradford, West Yorkshire BD7 1DP, UK

A B S T R A C T

The use of surface metrology microscopes to quantify surface texture is a powerful tool for the analysis of archaeological materials. Data collected from these microscopes allows for reliable and reproducible measurements of surface characteristics. However, archaeological materials provide some unique challenges for microscopic analysis, including archaeological objects that cannot leave museums or are too large to observe under a microscope. Because of these challenges, many researchers create molds and casts of an artifact's surface prior to measuring surface texture. The replicate surface is assumed to be an accurate representation of the original surface texture; however, limited testing has been done on the reliability of different molding compounds. This paper uses confocal microscopy to test the fidelity of different molding compounds for surface texture measurements. Results suggest that the objects' original surface texture can pose challenges to the accuracy of molds and the resulting casts, and that the intrinsic texture of the molding material impacts surface measurements of the replicated object.

1. Introduction

Archaeologists use replication as an analytical tool to understand material culture, whether it is through experimentation to imitate ancient gestures and technologies, or the careful recreation of artifacts for display in museums. In our increasingly digitized practice, we are becoming more concerned with the ability to produce replicas of archaeological materials with as much fidelity as possible. This is perhaps best illustrated in the use of high resolution 3D scanners and 3D printers, the archaeological applications of which have become more commonplace in recent years (e.g. Beale and Reilly, 2014; Earl et al., 2014; Grosman, 2016; Ioannides and Quak, 2014). These methods of three-dimensional digitization and replication are used as analytical, teaching, and display tools, allowing researchers to explore material objects in new ways. Through digital capture and replication, we can observe objects in greater detail, in new contexts, and with new insights. But replication does not necessitate the use of novel digital technologies. In this paper, we explore a more classic, low-tech form of replication—*molding*—and how this intersects with new methods of 3D microscopic surface quantification.

The archaeological method of use-wear analysis often analyzes molded artifacts instead of the original surface. The analysis of wear traces on archaeological materials provides insight into the function of an object; whether it is a stone tool or a tooth, wear processes change the surface texture of an object over time. Traditional use-wear analysis for both artifacts and teeth uses optical microscopy to visually identify wear features. Blind tests of lithic wear identification (e.g. Bamforth, 1988; Bamforth et al., 1990; Evans, 2014; Moss, 1987; Newcomer et al., 1986; Odell and Odell-Vereecken, 1980; Rots et al., 2006) and tooth wear identification (e.g. Mihlbachler et al., 2012) show that these optical methods are prone to misidentification, as well as inter- and intra-observer error. Therefore, recent research has taken a more quantitative approach to use-wear analysis, using microscopes developed for the field of surface metrology to quantify surface texture (e.g. Evans and Donahue, 2008; Evans and Macdonald, 2011; Evans et al., 2014; Faulks et al., 2011; Ibáñez et al., 2016; Macdonald, 2014; Scott et al., 2006; Scott et al., 2005; Stemp, 2014; Stemp et al., 2016; Stemp et al., 2008; Stemp et al., 2009; Stemp and Chung, 2011; Stemp et al., 2013; Ungar et al., 2008; Ungar et al., 2007; Ungar et al., 2016).

The creation of surface replicas with silicone molding materials is often an early stage in quantitative microscopic analysis before surface texture can be measured. Replicating the artifact's surface can be a two-step process, first a mold is taken of the surface, creating a negative imprint, and then a positive reproduction is cast from the mold for analysis. There are several reasons why a mold and subsequent cast might be made of an artifact. For example, often artifacts from museum

* Corresponding author.
E-mail address: danielle-macdonald@utulsa.edu (D.A. Macdonald).

https://doi.org/10.1016/j.jasrep.2018.02.033
Received 15 December 2017; Received in revised form 6 February 2018; Accepted 26 February 2018

collections cannot be removed for specialized analysis, or an object of interest cannot be detached from its context (such as teeth situated within a mandible). Another consideration is that frequently microscope objectives have close working distances; objects with highly textured form (large-scale surface topography) might not fit under the objective. Molds are also useful to document surface change over time and have been used in several use-wear experiments to document polish formation (e.g. Ollé and Vergès, 2014; Pedergnana and Ollé, 2017; Tumung et al., 2015).

The use of surface metrology instrumentation to quantify surface texture is still a relatively new method of analysis in archaeology. Researchers use a wide range of different techniques such as laser and white-light confocal microscopy (e.g. Evans and Donahue, 2008; Evans and Macdonald, 2011; Evans et al., 2014; Macdonald and Evans, 2014a; Scott et al., 2006; Scott et al., 2005; Stemp et al., 2016; Stemp and Chung, 2011; Stemp et al., 2013; Ungar et al., 2008; Ungar et al., 2007; Ungar et al., 2016; Xia et al., 2015), interferometry (e.g. Anderson et al., 2006; Astruc et al., 2011; Dumont, 1982; Vargiolu et al., 2007), profilometry (e.g. Stemp, 2014; Stemp et al., 2008; Stemp et al., 2009), atomic force microscopy (e.g. Faulks et al., 2011; Kimball et al., 1998; Kimball et al., 1995), and focus variation microscopy (e.g. Macdonald, 2014). Data collected from these microscopes allows for the quantification of three-dimensional surface texture, calibrated to standards developed by the International Organization for Standardization (ISO25178-2, 2011). Preliminary blind tests of surface measurements using laser-scanning confocal microscopy show that this quantification method performs better than traditional optical analysis conducted by an expert when identifying certain contact materials (Evans and Macdonald, in prep.). However, these microscopes are designed for engineering and industrial applications, and archaeological materials provide some unique difficulties for surface metrological analysis, as mentioned above. Thus, because of these challenges, many researchers create replicas of artifact surfaces using dentistry molding compounds to measure surface texture. The replicate surface is assumed to be an accurate representation of the original surface texture—a faithful copy—however, there have been few studies testing this hypothesis (although see Goodall et al., 2015, Rodriguez et al., 2009). To further complicate matters, very few molding companies publish the resolution specifications or dimensional change specifications for their products. Although no mold will be a perfect replica of the original surface, it is important to determine which molding compound will have the correct scale of resolution needed to address the archaeological question at hand. To address these issues, this preliminary study evaluates a range of common molding materials using laser-scanning confocal microscopy to test their resolution, precision, and accuracy for surface texture measurements of archaeological artifacts.

2. Background

Molding compounds are primarily manufactured for dental applications, and although some materials are made for engineering purposes, the majority of archaeological studies use dental molding compounds. To date, surface metrology studies conducted on lithic use-wear have not used molding materials to replicate the surface; however, as more researchers are beginning to experiment with surface metrology microscopes, the need to mold lithic objects is becoming increasingly relevant. In contrast, most dental microwear studies use molds and positive casts to replicate tooth surfaces prior to analysis. Teeth have more variable form topography (see Evans et al., 2014 for discussion of form, waviness, and roughness) than lithics and the close working distance of most surface metrology microscope objectives necessitates the creation of molds to enable microscopic evaluation of small areas. The most popular molding compounds that have been used in dental microwear studies include President's Jet Regular Body Dental Impression Material, manufactured by Coltène-Whaledent (e.g. Earl et al., 2014; Scott et al., 2006; Ungar et al., 2008; Ungar et al., 2016), and Provil® novo light, manufactured by Heraeus Kulzer GmbH (e.g. Beale and Reilly, 2014; Goodall et al., 2015; Ioannides and Quak, 2014; Schulz et al., 2010). Studies on bone taphonomy and cut marks have used Provil® novo light (Rodriguez et al., 2009), and Elastosil M4601 and 4512, manufactured by Wacker Chemie AG (Bello et al., 2011).

There are several steps needed to obtain molds and casts (see Camarós et al., 2016, Rose, 1983 for detailed instructions). The first stage is the cleaning process. Cleaning the object is essential so that dirt, grease, or other debris is not captured in the mold. These cleaning procedures should be non-destructive and tailored for the materials that are being replicated. Cleaning methods can range from lightly brushing the object with soap and water to chemical cleaning in an ultrasonic bath. After the object has been cleaned, the molding material is applied directly to the surface. Because molding materials are flexible, either several layers of the molding compound need to be applied, or a high-viscosity silicone material should be applied to the back of the mold to provide some stability (Camarós et al., 2016). Side 'walls' around the mold need to be created to allow the casting resin to be poured into the mold. Resin epoxies are mixed with a catalyst so that the resin will harden (each epoxy product will specify the epoxy to catalyst ratio) (Banks and Kay, 2003). The mixed epoxy catalyst is then poured into the mold and left to harden. This is best conducted in a vacuum to help remove air bubbles from the cast. Once the resin has set, the mold is carefully pealed from the cast and the cast is analyzed.

Many of the previous replication studies for microwear analysis were focused on testing visual differences such as observations of inconsistencies and deviations between molds or casts and the original surface, rather than comparing measurements of surface texture (e.g. Galbany et al., 2006; Williams et al., 2009). Recently, Goodall et al. (2015) tested a series of molding compounds to assess their precision and accuracy for the measurement of surface texture. In their study, Goodall et al. (2015) used focus variation microscopy (Alicona Infinite Focus) to test seven different molding compounds with a range of viscosities and chemical properties. They tested these materials on teeth, both a rough surface of dentine and a smooth enamel surface. Goodall et al. (2015) found that the seven tested molding compounds produced measurable differences between the replicated and the original surfaces. They found that molds from smoother enamel surfaces produced more variable measurements than the molds from the rough dentine surface. As well, measurements taken on molding materials with lower viscosity were highly variable; some low-viscosity materials demonstrated excellent precision and accuracy, while others had poor precision and accuracy. Low viscosity materials can be difficult to work with, even for expert users, so some of the variability might relate to the application of the molding compound. Furthermore, their research showed that high-viscosity molding compounds produced the lowest accuracy and precision overall, suggesting that the type of molding compound used is integral for reliable and reproducible measurement. Their results generate some interesting, yet troubling, questions about the fidelity of molds for surface metrology measurements. The study suggests that not all compounds are created equal, with some compounds producing molds that have surfaces with less accurate and precise measurements than others. However, one limitation of the study is that focus variation microscopy has trouble imaging smoother surfaces, which may have been a factor influencing some of the variability in measurements on the enamel surfaces (Macdonald, 2014). Thus, it is important to continue to test molding compounds to check the fidelity of the materials we are using to measure objects from the past.

Building upon this previous research, tested four different molding compounds that have been used by archaeologists but were not included in the initial study by Goodall et al. (2015). To acquire the measurements, laser-scanning confocal microscopy was used instead of focus variation microscopy, which was used by Goodall et al. (2015). Laser-scanning confocal microscopy was chosen because it has better results measuring smooth surfaces in comparison to focus variation microscopy (Evans and Macdonald, 2011). The resolution of each