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The effect of use duration on surface roughness measurements of stone tools

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The effect of use duration on surface roughness measurements of stone tools

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ABSTRACT

Laser scanning confocal microscopy has proved to be a promising technique in the identification of how prehistoric stone tools were used. Published research has shown that basic roughness parameters can characterise wear produced experimentally by different activities on the edges of stone tools (working different materials such as hide, wood and antler). However, it is important to understand other variables before these methods can be applied to archaeological artefacts. For example, it is not yet known how duration of use influences the texture characteristics of worn surfaces. This report presents a study of two contact materials (antler and wood) with variation in the duration of stone tool use. This research produces interesting results that indicate texture characteristics stabilise for antler but the results for wood working are more complex. The results instigate a discussion of sampling processes and future analytical strategies. This report presents the details of this research and other experiments that contribute to the development of applied methods in quantitative lithic microwear analysis.

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CONTENTS

FIGURES

TABLES

1 INTRODUCTION

Archaeology relies on the study of the cultural remains and associated materials to understand the activities of people in the past. In early prehistory, prior to the development of ceramics or metals, the majority of deposited cultural remains are stone tools. The analysis of these objects is a key factor in understanding early human behaviours including social organization, cognitive development, landscape use, changes in subsistence and mobility strategies. The best way to investigate these questions is to directly study how stone tools were used in prehistory thereby reconstructing past activities.

Stone tool specialists have developed the field of lithic microwear analysis to directly study stone tool function. The traditional technique used within this field is autoptic comparative microscopy that uses experimentally replicated and used tools as the comparative set. The microscopes used are generally Köhler illuminated reflective light microscopes at total magnifications ranging from 100× to 500×. Higher and lower magnifications are encountered less often and these use scanning electron microscopy or stereomicroscopy respectively. This traditional approach has a number of methodological flaws - the crucial flaw being the result of the highly interpretive autoptic approach to understanding tool function.

Blind test data of the traditional approach shows results that range from 16 % to 74 % accuracy (Evans and Macdonald 2011), a fact that has left the technique in low regard among archaeologists. These data have prompted attempts to improve the traditional approach and develop new approaches that could enable a more accurate assessment of tool use. These approaches have included image analysis (Grace *et al*. 1985; González-Urquijo and Ibáñez-Estévez 2003), edge damage quantification (Akoshima 1987; Bird *et al*. 2007), and micro chemical analysis (Christensen *et al.* 1992, 1993, 1998; Evans and Donahue 2005; Šmit *et al.* 1998, 1999).

Recent studies have taken a quantitative approach to lithic microwear analysis, using new technologies that generate measurements of surface topography, roughness parameters and profile paths across surface features (Evans and Donahue 2008; Evans and Macdonald 2011; Lerner *et al.* 2007; Stemp and Stemp 2001, 2003; Stemp and Chung 2011). These methods address the issues inherent in qualitative studies of lithic microwear analysis and are moving the field of archaeology forward towards a more scientific practice.

One documented experiment designed to study change in surface roughness characteristics as a function of use-duration has been published elsewhere (Stemp and Stemp 2003). In that paper a laser profilometer is used to study replica stone tools experimentally used to work wood. The wood was worked for 5000 strokes with intervals of 500 strokes. Between each set of strokes, profiles of the tool edge were recorded. The results of the work show no significant difference between the unused samples and the samples use to modify wood. In addition, the authors reported neither textural changes that can be used to distinguish used samples from unused samples, nor do they identify changes between the stages of tool use duration. Stemp and Stemp (2003) argue that this lack of identified changes could be the result of wood’s hardness in comparison to flint, presumably implying that there could be no actual textural change at the edges of the experimental tools as a result of use. However, autoptic analysis of specimens used to work wood clearly display different surface textures as a result of wear processes (*ibid*). The authors also refer to the variable development of worn surfaces on tools used to work wood in previous published experimentation and suggest that the lack of worn surface development may be a factor. Their own published images do show a minor visual difference in texture but the published micrographs are not sufficient to allow the reader to see whether there are textural changes along the tool edges and to what degree this has occurred. It can be suggested that the nature of profilometry sampling is a potential causal factor in the results of this experiment along with the unfiltered approach to data analysis. The profilometer requires long straight sections of tool edge that have been modified by a wear process to collect suitable data. The collected data is also treated in a non-discriminant way. The reticulated nature of textural changes of the surface as a result of tool use against wood means that sampling in this way collects data from parts of the edge that exhibit no changes in texture resulting from wear. Therefore, even if the profiles are collected along a worn portion of edge, without a filtering protocol to reduce sampling from unused sectors, the collected data is likely to be overwhelmed by the background noise signature of the unworn tool surface.

1.1 AIM

A simple experiment setup was designed to test the tribological evolution of lithic tool surface texture used to work different contact materials. The hypothesis was that worn surfaces have unique surface texture characteristics based on the contact material, regardless of use duration. Antler and wood were chosen as the two contact materials. The working of these materials represents different activities that are important to a cultural understanding but they are classically difficult to differentiate using traditional microwear methods (*e.g.* Keeley 1980); a point borne out in the detailed analysis of blind test results which show antler working tools are misinterpreted as wood working tools 30 % of the time (Evans 2009). The secondary aim of the experiment was to find areal surface texture parameters (ISO/FDIS 25178-2: 2010) that can differentiate the worn surfaces produced by these two contact material processes through surface texture parameters.

2 EXPERIMENTAL SET-UP

This experiment was designed to study the development of worn surfaces on stone tool artefacts by producing a series of tools that are used, studied using imaging confocal microscopy (Leach 2011 describes confocal microscopy in the context of surface topography measurement), and used again in series. This process provided a sequence of topography maps showing the same tool as wear processes modified its surface. The experiment was designed with four separate stages, beginning with the first stage where the tools were analysed prior to use. The second stage of the series included tools used for 1000 strokes, with each subsequent stage adding an additional 1000 strokes up to 3000.

A set of eight flint artefacts were produced from a nodule of English chalk flint (Brandon flint, figure 1**)**. These experimental artefacts are similar in form and raw material to Early Prehistoric artefacts. The pieces were modified with the removal of small flakes along one edge to facilitate holding without a handle. The opposite, unmodified edge on each tool was used as the contact edge for the experiments. Four artefacts were selected from the group, based on their straight profile and straight cutting edge, to be used in the experiments. Two of these were chosen to work antler (No 13 and No 15) and the other two were used to work wood (No 16 and No 17). The tools were used by two different investigators, each investigator using a tool on each of the contact materials. The motion of tool use was unidirectional and perpendicular to the surface of the contact material (whittling/scraping) at a low angle (approximately 20°). Tools were used for 1000, 2000 and 3000 strokes. As the experiment was designed to observe the development of wear, tools were prepared for observation prior to the first use, and after each set of use.

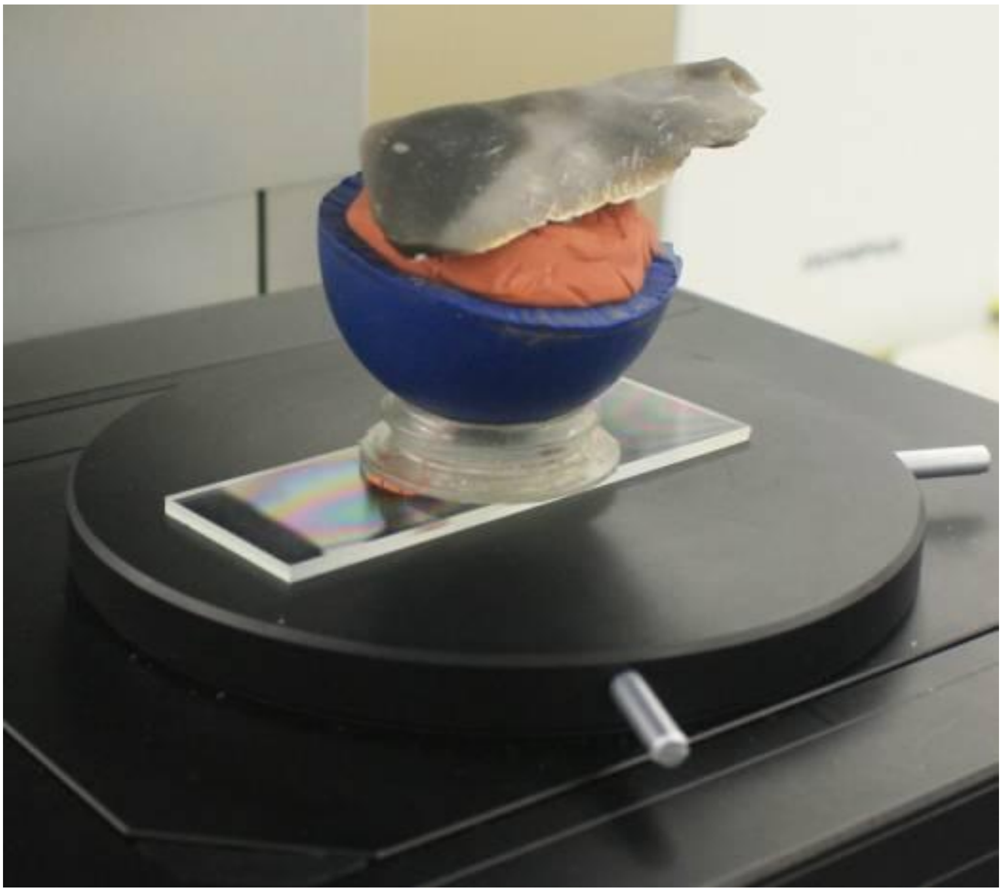

Figure 1 Example of chalk flint mounted for measurement

Preparation for observation followed dipping in a 10 % solution of Nutratek® and brushing with a soft bristle brush before rinsing under running water. This was followed by soaking in 10 % KOH for ten minutes, rinsing, and soaking in 10 % HCl for ten minutes before bathing in water for a further ten minutes. Tools were prepared before analysis using iso-propanol. To ensure small fragments of tissue and dust were removed from crevasses the tool surfaces were coated in AccuTrans® AB (Coltene-whaledent) which was peeled from the surface after setting.

The four tools were measured with an imaging confocal microscope (ICM) (Leach 2011). The ICM was an Olympus LEXT OLS4000 (see figure 2) fitted with a 50× magnification objective lens (0.95 numerical aperture, working field of view of 0.26 mm by 0.26 mm and sampling distance of approximately 0.25 µm), and a 100× magnification objective lens (0.95 numerical aperture, working field of view of 0.13 mm by 0.13 mm and sampling distance of approximately 0.13 µm).

Figure 2 Imaging confocal microscope used (Olympus OLS 4000)

Prior to use, five measurement areas were chosen on the surface of the tool surface along the cutting edge. Once this data was collected, the tools were used to whittle their respective contact materials for 1000 strokes. After interaction with the contact material each tool was re-prepared for measurements, including cleaning. Five areas of the worn surface were identified along the edge of each tool for measurements; these areas were chosen based on the extent of wear features along the edge. For each subsequent stage of the experiment (2000 and 3000 strokes) the investigators endeavoured to measure the tools in the same five areas chosen after the second stage (1000 strokes).

The areal data was analysed using commercially available surface texture analysis software (MountainsMap version 5).

3 ANALYSIS

Development of wear on the artefacts worked on antler (No 13 and No 15) was well-defined (visible) compared to the wear developed on the wood worked artefacts. The wear produced by antler was visible on the full field of view of the 50× magnification objective lens (figure 3a), whereas the wear produced by wood was visible only on the upper side of the field of view of the 100× lens (figure 3b). As a result, the filter selection and the analysis strategy applied to the measurement results were slightly different from antler to wood worked artefacts.

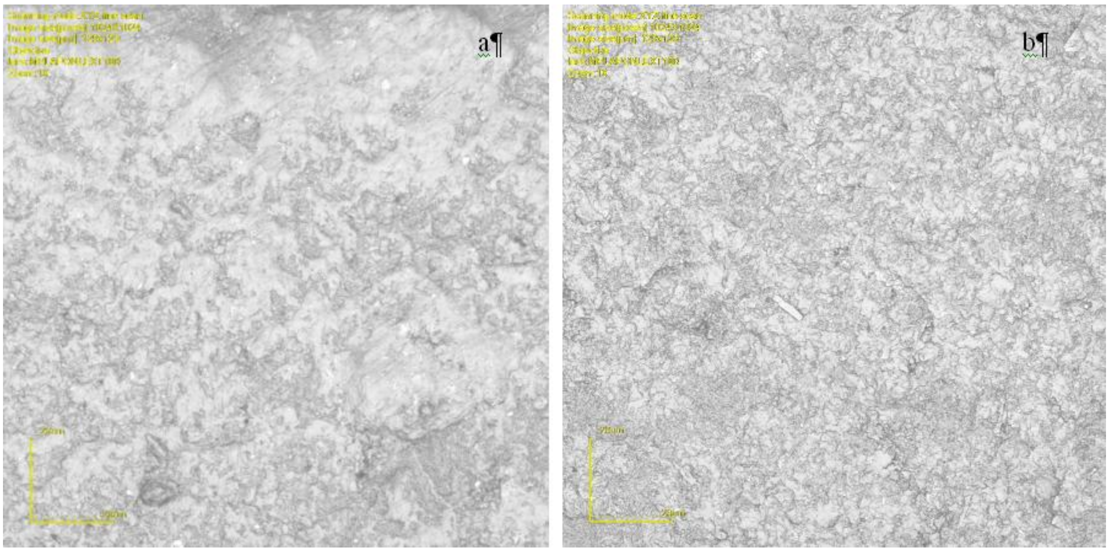

Figure 3 Sample images: a - 50× magnification objective lens measurement on antler worked samples; b - 100× magnification objective lens measurement on wood worked samples

Various combinations of areal filters (S-filter, L-filter and F-operator – see ISO/DIS25178 part 3 and Leach 2009) were investigated. The successful combinations of S/L-filters that provided a measurable change in areal parameters are presented in table 1.

Table 1 S/L filter selection

Filters	Antler	Wood
S-filter /µm	2.5	1
L-filter /µm	50	25

The measurements taken at the stage prior to use were used as the control measurements. The average value of the areal parameters calculated using the five measurements acquired at the first stage (${}^{0}\bar{S}x$) were subtracted from the average values of the same parameters calculated at the other three stages (${}^{i}\bar{S}x$), see equations (1). The areal parameters were considered to correlate with the development of wear if the three calculated differences (${}^{i}\delta_{Sx}$) respected simultaneously two conditions: the values of all three differences had to be larger than the corresponding combined standard deviations of the means (${}^{i}\sigma_{c}$); and the same three values of difference of the parameter had to have the same sign.

$$\begin{cases} {}^{i}\delta_{Sx} = {}^{i}\bar{S}x - {}^{0}\bar{S}x \\ {}^{i}\sigma_{c} = \sqrt{{}^{i}\sigma_{\bar{S}x}^{2} + {}^{0}\sigma_{\bar{S}x}^{2}} \end{cases}, \qquad (1)$$

where, ${}^{0}\sigma_{\bar{S}x}$ is the standard deviation of the mean value of the areal parameters calculated at the first stage and ${}^{i}\sigma_{\bar{S}x}$ is the standard deviation of the mean value of the areal parameters calculated at the other three stages.

Tiling the measurement results, levelling each tile using a least squares algorithm (F-operator) and averaging the areal parameters calculated on each tile further increased the sensitivity of the areal parameters with the wear process. The size of the tile corresponded to the size of the L-filter, such that the antler tile was a square with the side equal to 50 µm (figure 4) and the side of the wood tile was equal to 25 µm (figure 5). The measurements acquired with the 50× lens were used to analyse antler worked samples whereas the 100× lens measurements were used to analyse the wood worked samples.

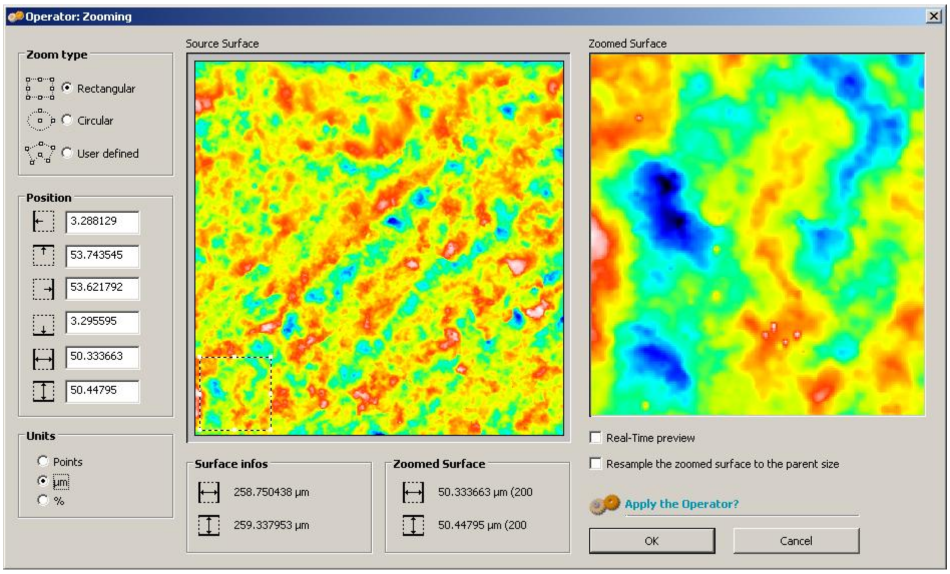

Figure 4 Example of tiling operation of 50× lens measurement using Mountains software

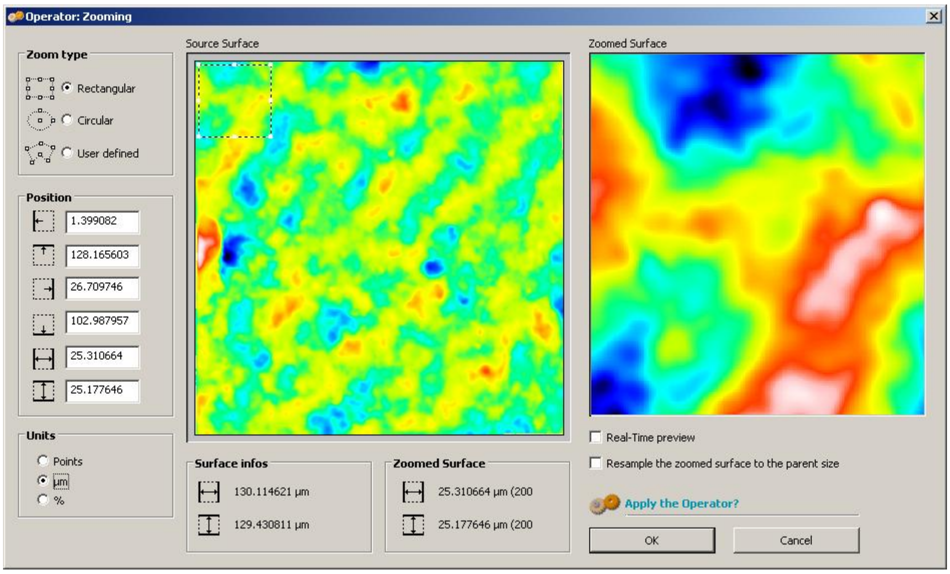

Figure 5 Example of tiling operation of 100× lens measurement using Mountains software

Each of the antler 50× lens measurement results was split in to twenty-five tiles. In the case of the wood 100× lens measurement results, only ten tiles were used that came from the top of the image, which corresponded to the area closer to the cutting edge of the samples. The areal parameters were calculated on every tile and used to work out the average value of the parameters and the corresponding standard deviation of the mean over the number of tiles used at each stage of the process. Therefore, the average value of the parameters was calculated using the results from 125 tiles (five measurement areas with twenty five tiles each) in the antler case and from fifty tiles (five measurement areas with ten tiles each) in the wood case.

4 RESULTS

4.1 ANTLER

Antler wear developed well on both samples (No 13 and No 15) and eleven areal parameters appear to be correlated with the wear process. The common parameters that changed on both antler samples were found to be *Sq*, *Sv*, *Sz*, *Sa*, *Smr* (c = 1 µm under the highest peak – pre-set value in the software), *Smc* (p = 10 % – pre-set value in the software), *Sxp* (p = 50 % q = 97.5 % – pre-set value in the software), *Sdq*, *Vv* (p = 10 % – pre-set value in the software) and *Vmc* (p = 10 % q = 80 % – pre-set value in the software) – see table 2 and table 3. The top three parameters were *Sz* (figure 6), *Smr* (figure 7) and *Smc* (figure 8). The description of the areal parameters is given in the Appendix.

Although the antler results show a set of parameters correlated to the development of wear, the absolute values of the areal parameters are different between one sample and another such that it is not possible to provide an absolute value for the areal parameters that that would indicate antler wear. In addition, areal parameters do not show that the antler wear development is different with the number of subsequent strokes, which indicates that the wear flattens out before 1000 strokes measurements were taken.

Table 2 Parameters sensitive to wear on sample No 13 (σ = standard deviation)

No of strokes	*Sq* value /µm	*Sq* σ /µm	*Sv* value /µm	*Sv* σ /µm	*Sz* value /µm	*Sz* σ /µm	*Sa* value /µm	*Sa* σ /µm
0	0.79	0.05	1.44	0.14	4.6	0.2	0.64	0.04
1000	0.61	0.05	1.02	0.08	3.8	0.4	0.49	0.03
2000	0.64	0.07	1.10	0.13	3.3	0.4	0.53	0.05
3000	0.60	0.05	1.03	0.09	3.3	0.3	0.49	0.04

No of strokes	*Smr* value /%	*Smr* σ /%	*Smc* value /µm	*Smc* σ /µm	*Sxp* value /µm	*Sxp* σ /µm	*Sdq* value	*Sdq* σ
0	3	1	1.12	0.07	0.98	0.11	0.42	0.02
1000	6	2	0.85	0.05	0.69	0.07	0.36	0.04
2000	13	3	0.92	0.10	0.78	0.11	0.32	0.02
3000	13	3	0.85	0.07	0.78	0.11	0.32	0.02

No of strokes	*Vv* value /µm^3 µm^{-2}	*Vv* σ	*Vmc* value /µm^3 µm^{-2}	*Vmc* σ	*Vvc* value /µm^3 µm^{-2}	*Vvc* σ
0	1.17	0.07	0.68	0.05	1.12	0.07
1000	0.89	0.05	0.51	0.04	0.86	0.05
2000	0.95	0.10	0.58	0.06	0.91	0.10
3000	0.89	0.08	0.58	0.06	0.85	0.07

Table 3 Parameters sensitive to wear on sample No 15 (σ – standard deviation)

No of strokes	*Sq* value	*Sq* σ	*Sv* value	*Sv* σ	*Sz* value	*Sz* σ	*Sa* value	*Sa* σ
	/µm							
0	0.55	0.14	0.79	0.16	3.8	0.9	0.44	0.09
1000	0.35	0.06	0.55	0.10	2.1	0.4	0.29	0.05
2000	0.33	0.04	0.52	0.08	1.8	0.3	0.27	0.03
3000	0.30	0.04	0.50	0.09	1.6	0.3	0.25	0.03

	Smr value	*Smr* σ	*Smc* value	*Smc* σ	*Sxp* value	*Sxp* σ	*Sdq* value	*Sdq* σ
	/%		/µm					
0	7	2	0.75	0.14	0.55	0.13	0.50	0.23
1000	25	6	0.50	0.08	0.38	0.07	0.25	0.03
2000	31	6	0.47	0.06	0.37	0.07	0.22	0.02
3000	31	6	0.44	0.06	0.37	0.07	0.22	0.02

	Vv value	*Vv* σ	*Vmc* value	*Vmc* σ	*Vvc* value	*Vvc* σ
	/µm³ µm⁻²					
0	0.79	0.15	0.44	0.08	0.77	0.15
1000	0.53	0.09	0.30	0.05	0.51	0.08
2000	0.49	0.07	0.29	0.04	0.47	0.06
3000	0.45	0.06	0.29	0.04	0.44	0.06

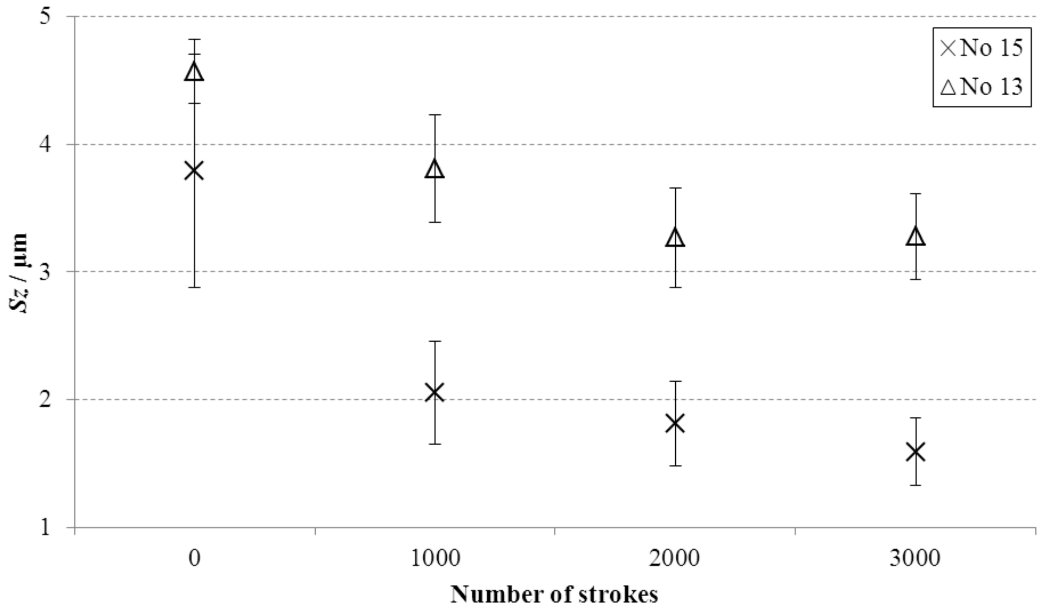

Figure 6 *Sz* results on antler samples

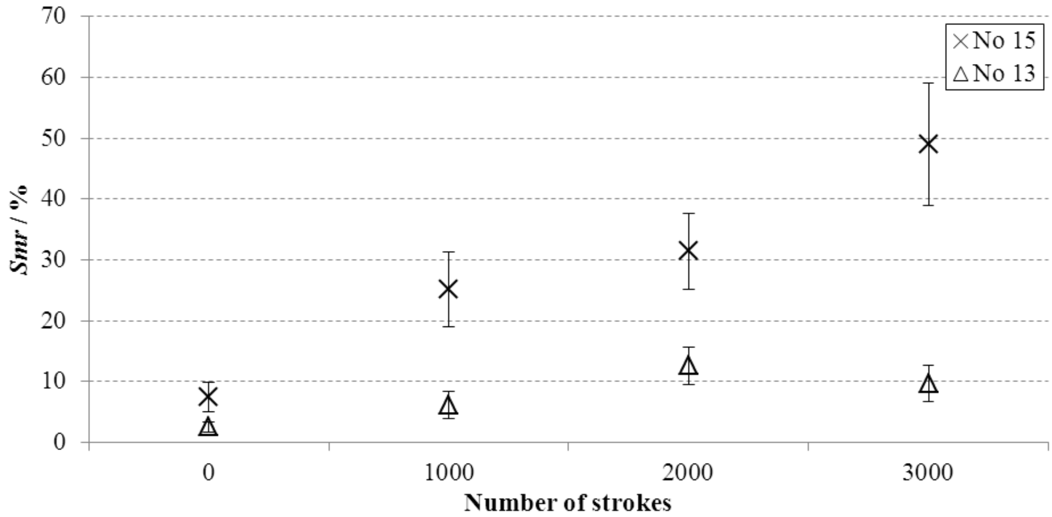

Figure 7 *Smr* results on antler samples

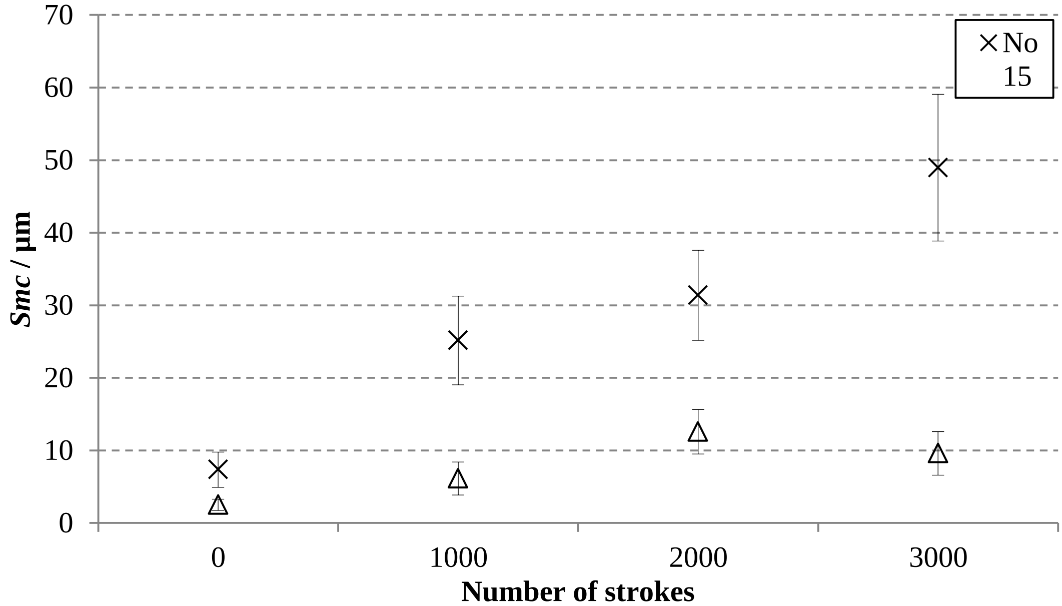

Figure 8 *Smc* results on antler samples

4.2 WOOD

The wood worked wear on samples No 16 and No 17 did not produce a measurable change in the surface of the samples that could be identified with a common areal parameter. Some parameter change on sample No 16 (*Sdr*, *S5v*, *Sda* and *Sdv*) was recorded.

In contrast to the antler samples, the wood wear development is visible after 1000 strokes. This behaviour can be monitored using the measurements taken at the 1000 stroke stage as the control measurements. The average value of the areal parameters calculated using the five measurements acquired at the 1000 stokes stage were subtracted from the average values of the same parameters calculated at the other two stages, 2000 strokes and 3000 strokes, respectively. *Sq*, *Sa*, *Sdq*, *Sdr* and *Vvc* were found to correlate with wear development (see table 4 and table 5). The top three parameters were *Sa* (figure 9), *Sdq* (figure 10) and *Sdr* (figure 11).

Table 4 Parameters sensitive to wear on sample No 16 (σ – standard deviation)

No of strokes	*Sq* value	*Sq* σ	*Sa* value	*Sa* σ	*Sdq* value	*Sdq* σ	*Sdr* value	*Sdr* σ	*Vvc* value	*Vvc* σ
	/µm						/%		/µm^3 µm^{-2}	
0	0.498	0.020	0.407	0.018	0.264	0.005	3.45	0.13	0.59	0.03
1000	0.594	0.033	0.477	0.028	0.349	0.014	6.06	0.49	0.72	0.05
2000	0.538	0.028	0.436	0.023	0.315	0.011	4.92	0.33	0.65	0.03
3000	0.479	0.024	0.386	0.019	0.315	0.011	3.86	0.36	0.72	0.05

Table 5 Parameters sensitive to wear on sample No 17 (σ – standard deviation)

No of strokes	*Sq* value	*Sq* σ	*Sa* value	*Sa* σ	*Sdq* value	*Sdq* σ	*Sdr* value	*Sdr* σ	*Vvc* value	*Vvc* σ
	/µm						/%		/µm^3 µm^{-2}	
0	0.470	0.023	0.377	0.019	0.323	0.013	5.17	0.41	0.567	0.030
1000	0.502	0.017	0.409	0.014	0.316	0.008	4.91	0.24	0.605	0.019
2000	0.472	0.023	0.381	0.019	0.294	0.006	4.27	0.18	0.569	0.029
3000	0.413	0.022	0.328	0.018	0.294	0.006	4.01	0.22	0.605	0.019

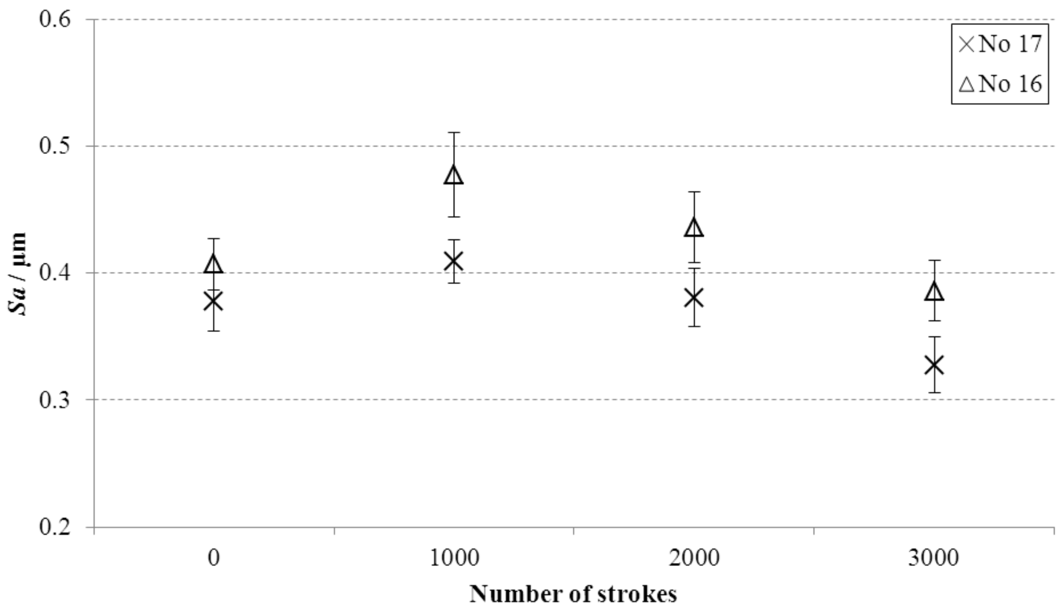

Figure 9 *Sa* results on wood samples

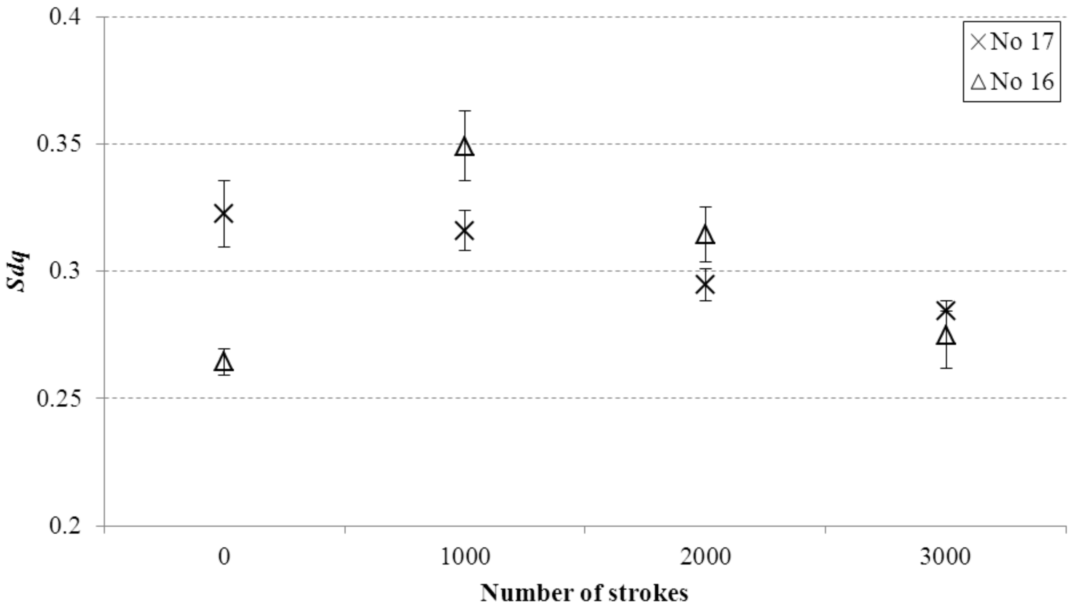

Figure 10 *Sdq* results on wood samples

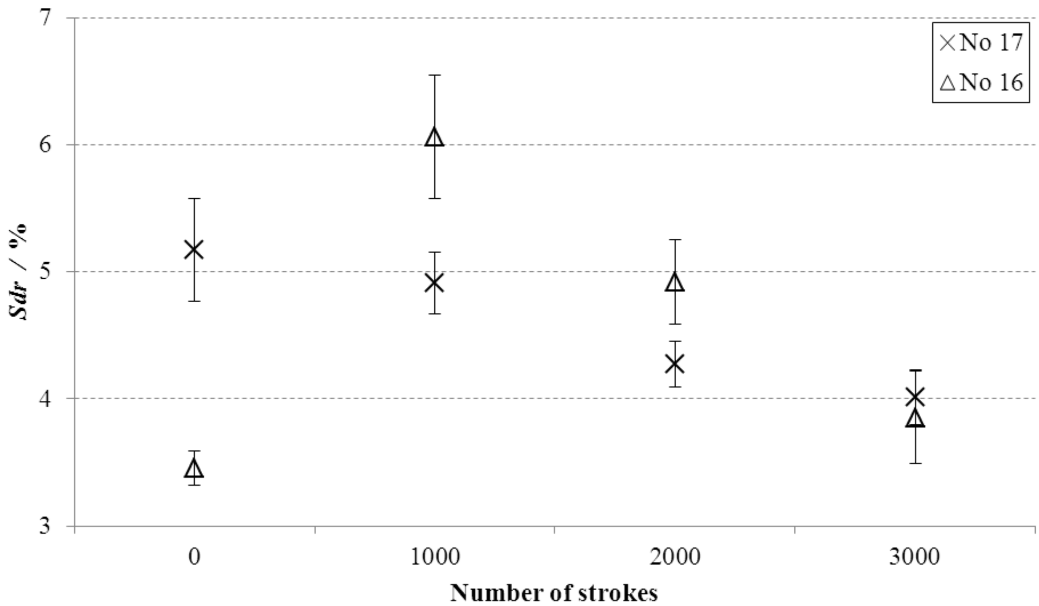

Figure 11 *Sdr* results on wood samples

5 CONCLUSIONS

Antler worked samples present clear indication of wear development that is given by both visual inspection and change between the un-worked and worked surfaces' areal parameters. The wear produced by antler work on the flint artefacts does not introduce a measurable difference in areal parameters after 1000 strokes, which indicates that the wear development plateaus before 1000 strokes. This supports the hypothesis that, once developed, the texture of worn surfaces remains consistent. However, due to the large difference in the values between the areal parameters calculated on the two samples it is not possible to specify any parameter value that is characteristic of the wear produced by the antler work. The results of this research contradict those presented in previous research (Evans and Donahue 2008), which found that several areal parameters can be used to characterise worn surfaces generated by different working processes, including antler working. This contradiction may be ascribed to differences in sampling processes. The semi-automated sampling process used in this study results in some sampling from unworn portions of tool surfaces. Since the area of worn surface varied between locations on different tools studied, this will inevitably have resulted in variation in results between the tools. In the future it is suggested that the processes of sampling used in this type of research need to be evaluated to ensure consistency between experimental sets.

Wood working wear was not well developed and no variation in areal parameters was recorded between the worked and un-worked surfaces, although some wear indication was visible. This can be explained by the fact that the measurement areas on un-worked samples did not coincide with the measurement areas on the worked samples. A number of areal parameters indicate wear development when changing the control to the 1000 strokes stage measurements. The values of the areal parameters calculated on the two samples are similar.

Future work is required for more insight into the development of wear. The number of samples worked with one material has to be increased. More incremental steps are required below 1000 strokes on the antler case and above 3000 strokes on the wood case. It is possible that areal feature parameters (Leach 2011) could also help but different pruning ratios than the pre-set software ratios have to be investigated.

Acknowledgements

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APPENDIX - LIST OF USED AREAL PARAMETRS AND THEIR DESCRIPTION

Parameter	Description
Sa	Arithmetical mean height
Sq	Root mean square length of the scale limited surface
Sv	Maximum pit depth
Sz	Maximum height of the scale limited surface
Sdq	Root mean square gradient of the scale limited surface
Sdr	Developed interfacial area ratio of the scale limited surface
Smr(c)	Area material ratio of the scale limited surface
Sdc(mr)	Inverse areal material ratio of the scale limited surface
Sxp	Peak extreme height
Vv(mr)	Void volume
Vvc	Core void volume of the scale limited surface
Vmc	Core material volume of the scale limited surface