Breaking free from the constraints of strength: Rethinking the Role of Archaeological Adhesives in Prehistoric Hafting Systems.

Ronè Oberholzer [1¶*], Veerle Rots [1, 2,¶]

¶ These authors contributed equally to this work.

[1] TraceoLab, University of Liège, Belgium
[2]F.R.S.-FNRS, Belgium

***Corresponding author**
rone.oberholzer@uliege.be

¶ These authors contributed equally to this work.

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Abstract

This study explores the impact of lithic substrate variability on joint design, aiming to enhance the understanding of archaeological adhesives through mechanical testing. While previous research has shown that adhesive shear strength can vary with different recipes, few studies have examined the behaviour of adhesives on irregular, knapped lithic substrates typical of archaeological contexts. To address this, we conducted lap shear tests using these authentic materials to bridge the gap between controlled laboratory experiments and real-world archaeological conditions. Our findings suggest that joint design and the axial application of force significantly influence bond performance, posing challenges when using uneven lithic substrates. This highlights the need to reconsider whether current testing methods fully capture the behaviour of adhesives under such conditions. Mechanical tests can provide insights into certain material properties, but they should be used selectively to address specific questions, avoiding direct and potentially inappropriate extrapolations to prehistoric or archaeological contexts. While often a focus in modern testing, shear strength may not have been the primary function of many adhesives. Instead, these adhesives likely played non-structural roles, such as sealing, stabilising, or moulding, suggesting the need to complement current testing approaches with alternative methods that better reflect their intended uses. By rethinking adhesive categorisation and function, future research can build on existing methods to gain a more comprehensive understanding of the diverse properties of archaeological adhesives.

Keywords: Palaeolithic period, stone tools, residues, adhesives, mechanical tests, experimental archaeology, early modern humans and Neanderthals,

Data and materials availability: All data and materials used in the analyses are reported in the Main Text or the Supplementary Information.

1. Introduction

Archaeological adhesives have been interpreted as serving various functions in prehistoric tool and weaponry systems, including attachment of stone tips or insets to shafts, facilitating the detachment of projectile elements from prey, securing handles, or bonding components in multi-part weapons. In recent decades, the study of adhesives has been used in debates surrounding the cognitive abilities of *Homo sapiens* and Neanderthals. Compound recipes, where ingredients are combined to change into adhesives irreversibly, have been extensively discussed and, in some cases, used as proxies for studying past behaviour, especially regarding *H. sapiens* in Southern Africa [1–8]. More recently, tar production [9] has been linked to *H. sapiens* in southern Africa and used to argue for cognitive complexity, although this has been recently questioned by others[10] . Cognitive complexity arguments have also been made regarding Neanderthals based on adhesive usage. Tar, pitch, and bitumen necessitated the control of fire along with time and resource investment [7,11–14]. A recent discovery of a potential hearth used for tar production suggests an even greater level of investment creating specialized heating structures [15] . Despite recent debates on simpler methods for birch tar production [16], the production and use of these adhesives are still seen as showcasing the high cognitive abilities of Neanderthals [7,13,17,18]. Researchers have analysed different types of adhesives and production methods to evaluate and sometimes contrast the cognitive skills of these two species [1,8,17,19–21]. Inference possibilities and the desire to understand adhesive performance, have led researchers to dedicate attention not only to identifying adhesive ingredients but also to unravel their production process. In a growing group of studies, these different production processes and recipes have been compared using several experimental approaches. For instance, Gillard [22] conducted realistic shooting experiments to assess the effect of rosin content in a rosin-beeswax adhesive mixture. Wadley [5] investigated the impact of ochre addition on drying times and user-friendliness. Kozowyk [23] employed rheological analyses, Vickers hardness tests, and thermogravimetric analysis to evaluate the impact resistance and peel resistance of different adhesive formulations. Among these methods, mechanical testing—particularly the evaluation of adhesive shear strength—has emerged as one of the most commonly used approaches to assess the performance of archaeological adhesives. Mechanical tests combined with

ASTM international standards are a way in which the shear strength of glues can be tested in a standardised manner.

Studies conducted so far on the mechanical properties of adhesives have explored a range of additives such as charcoal. [18] and ochre [2,5,23,24], ingredient ratios [2,22,24], grain sizes [25], and various production methods that impact shear strength [9,14,16,18,26]. Comparative studies have been conducted to assess the strength of bitumen, tar, resins, gums, and latex. [9,14,18,23,24,27]. A smaller set of investigations has looked at substrate influences like the influence of an organic haft. [24] and surface roughness [25]. A common theme across all these studies is that whichever variable the experimental approach tested, seems to influence the strength of the adhesive (suppl. Table S3 and S4).

Zipkin et al. [25], found that the roughness and particle size of additives influenced the strength of their joints. Kozowyk et al. [2] used ASTM D1002 and D950 standards and concluded that the ratio of ingredients in ochre, resin and beeswax recipes influenced the strength of the joint. In a later investigation, Kozowyk et al.[18] explored the impact of ambient temperatures and various cooking times for pine tar, finding both to affect joint strength significantly. Additionally, their study analysed different ratios of additives in tar, reinforcing their earlier conclusion that ingredient proportions in adhesive mixtures play a crucial role in joint strength. Schmidt et al. [9] tested plant secretions and found that, beyond the diverse results for different plant exudates, the drying times of some also influenced their strength. This study also tested *Podocarpus* tar made with different methods and found differences in the strengths based on production method. Different production processes specifically related to birch tar have similarly been shown to influence the strength of joints in multiple studies [26,28]. To date, only one study has delved into the influence of organic haft types on joint strength. The experiment done by Tydgadt and Rots [24] found that different combinations of organic hafts and adhesives produced varying results. This study also found that the ratio of ochre affected the joint strength.

This study aims to build on previous research by exploring how variations in lithic substrate affect joint design. We used a range of rock types to examine how differences in coarseness and fracture planes influence performance. Since the shear strength of an adhesive from a small single-lap specimen can vary when used with different adherents (https://www.astm.org/d1002-10r19.html), we conducted lap shear tests using knapped lithic substrates to better replicate archaeological conditions. This approach allows us to more accurately simulate archaeological conditions and assess whether particular raw materials contribute to stronger hafting joints.

2. Materials & Method

The experimental protocol comprised two phases. In the initial phase, the focus was on assessing the impact of variables identified as influential in adhesive mechanics. In phase two, all variables seen to have exhibited an influence during phase one were accounted for while replacing one of the substrates with a knapped lithic.

2.1 Substrates

Throughout phase 1, substrate A (a pine wood haft with a 12 mm width) and substrate B (a glass slide with a thickness of 6 mm and a width of 27 mm) remained constant. Recognizing the crucial role joint design plays in adhesive mechanics, in phase 2 of the study knapped lithic substrates were introduced as a substrate to simulate archaeological conditions more closely. For this phase substrate A was once again held constant, consisting of a pine wood haft with a width of 0.7 cm. The adjustment in haft width in this phase was made to accommodate the smaller dimensions of the lithics employed as substrate B. These lithics were knapped from diverse raw materials typically used by humans to manufacture stone tools, including obsidian, quartz, quartzite, flint, and dolerite. Expert knapper C. Lepers (20 years of experience) manufactured all blanks and blanks were incorporated in the experimental reference collection TRAIL of TraceoLab.

2.2 Adhesives

For this study, we aimed to use an adhesive that had proven effective in previous research. and therefore relied on the results of a study by Tydgadt & Rots (2022). Among the options they tested, Arabic gum showed the highest break force at 518 N per cm^2, but since the Arabic gum used in the study was commercially sourced, we decided to explore alternative adhesives. The next best-performing adhesive in terms of break force was a resin-beeswax mixture, with and without the addition of ochre [24]. Although the mixture containing ochre demonstrated slightly better mechanical performance, its results were more inconsistent compared to the simpler recipe of resin and beeswax alone. Due to this variability, we chose the resin-beeswax adhesive for our study. Thus, for this study, a mixture using 70% pine resin (harvested) and 30% beeswax (harvested) was used and this adhesive mixture was consistent for both phases of the test.

2.3 Mechanical tests

All tests were done with a SHIMADZU (autograph G-S-X) test bench. Substrate A was clamped, and substrate B was positioned on a wooden surface. Shear compression force was applied until the joint failed. The shear force necessary to break the joint was recorded and divided by the surface area that was glued to convert the measurement to Newton per cm^2.

2.4 Statistical Tests

The statistical analysis was done with Jamovi version 2.3.21.0. A Games-Howell Post-Hoc Test (unequal variances) was conducted in the second experimental phase. This test was chosen as the data did not pass the Levenes' homogeneity of variances test.

2.5 Experimental Procedure

All joints were glued, and the variables outlined in Table 2 were implemented. Following a minimum drying period of 24 hours, the joints were subjected to testing. In the test setup, substrate A was securely clamped, while substrate B was placed on a wooden surface. A shear compression force was then applied until the joint ultimately failed.

During the first phase, a control group was formed in which all identified influential variables were kept constant. The performance of this control group was then compared against all other subphases within the initial phase. This was done to determine the impact of each variable on the success of the joint in comparison to the control group. Variables subjected to modification in this phase included setting temperature, the thickness of glue coating, substrate cleanliness, the viscosity of the adhesive during the application, and the size of the glued area (Table 2).

Table 2: Variables controlled for experimental phase 1.

Variable tested	Setting time	Temperature	Clamped	Surface cleaned	Viscosity	Continuity	Surface area	#
Control	Minimum of 24h	19°C	No	Yes	Low	Continuous layer	1.8 cm^2	10
Low Temperature	Minimum of 24h	**7-11°C**	No	Yes	Low	Continuous layer	1.8 cm^2	5
Glue thickness	Minimum of 24h	19°C	**Yes**	Yes	Low	Continuous layer	1.8 cm^2	5
Cleaned surface	Minimum of 24h	19°C	No	**No**	Low	Continuous layer	1.8 cm^2	5
Viscosity	Minimum of 24h	19°C	No	Yes	**High**	Continuous layer	1.8 cm^2	5
Surface area	Minimum of 24h	19°C	No	Yes	Low	Continuous layer	**1.2 cm^2**	5
Surface area	Minimum of 24h	19°C	No	Yes	Low	Continuous layer	**2.4 cm^2**	5
Surface area	Minimum of 24h	19°C	No	Yes	Low	Continuous layer	**4.8 cm^2**	5

Acknowledging the vital role of joint design in adhesive mechanics, the study's second phase incorporated knapped lithic substrates to more accurately simulate archaeological conditions. While doing so, it maintained the key variables identified in phase one to ensure optimal success without interference from other factors.

Table 3: Variables controlled for experimental phase 2.

Raw material Used	Setting time	Temperature	Clamped	Surface cleaned	Viscosity	Continuity	Surface area	#
Dolerite	Minimum of 24h	19°C	No	Yes	Low	Continuous layer	1.05 cm^2	12
Flint	Minimum of 24h	19°C	No	Yes	Low	Continuous layer	1.05 cm^2	12
Obsidian	Minimum of 24h	19°C	No	Yes	Low	Continuous layer	1.05 cm^2	12
Quartzite	Minimum of 24h	19°C	No	Yes	Low	Continuous layer	1.05 cm^2	12
Quartz	Minimum of 24h	19°C	No	Yes	Low	Continuous layer	1.05 cm^2	12

3. Results

The primary objective of the initial mechanical test was to discern the variables exerting influence on joint success in comparison to the control group. In the control group, with a stable setting temperature of 21°C, unclamped joints, slightly less viscous glue and acetone-cleaned substrates the mean bond strength was 153 N/mm² (Table 4). For the controlled samples, the internal variation was also the lowest, with a CV of 20.6%. The mechanical tests revealed that the performance of the pine resin and beeswax adhesive was highly sensitive to environmental conditions, application techniques, and substrate preparation. Lower setting temperatures significantly weakened the adhesive bond, suggesting that temperature plays a critical role in curing and bonding strength. Clamping the joints during drying further reduced bond strength, potentially due to the altered distribution of the adhesive under pressure. Applying the glue in a highly viscous state and using uncleaned substrates both resulted in weaker bonds, underscoring the importance of proper adhesive consistency and substrate preparation for optimal adhesion. Variations in surface area showed non-linear effects. This concept aligns with Petrie's (2007) observation that the relationship between surface area and joint strength isn’t straightforward. Other than surface area the findings indicate that joint strength is directly affected by all the variables examined in phase one, making it crucial to manage these factors effectively to enhance adhesive performance.

Table 4: Statistical information of experimental phase 1 in N per cm^2.

Variable	N	Failed	Mean	Median	Coefficient variation	Minimum	Maximum
Control	10	0	153	168	20.6	68.8	177
Setting temperature 7-15°C	5	0	73.7	56.7	39.7	41.7	115
Joint clamped	5	0	63.2	57	26.9	34.1	103.2
High viscosity	5	0	97.2	77.1	44.3	44.9	150
Substrates not cleaned	5	0	91.3	67.3	62.4	20.3	182

Surface area 1.2cm^2	3	2	82	55.5	63.2	36	155
Surface area 2.4cm^2	5	0	151	129	55.2	53.9	261
Surface area 4.8cm^2	5	0	86.1	64.1	60.2	51.7	189

The second phase introduced knapped lithic substrates to look at the influence of rock types. The results of phase two are summarised in Table 5. Flint, which is a sedimentary rock, has a smooth conchoidal fracture and a micro- to cryptocrystalline structure. The nature of flint makes the fracture pattern of this material predictable. The experimental blades exhibited mainly smooth surfaces with a conchoidal fracture pattern, and their overall morphology was relatively straight. The results from the tests with flint displayed a mean break force of 67.1 N per cm² with a slightly lower median of 53 N per cm^2. Despite greater morphological consistency compared to other raw materials, there were still some challenges in achieving parallel hafting.

The igneous rock types used were obsidian and dolerite. Obsidian, characterised as volcanic glass, has an aphyric texture due to rapid magma cooling, resulting in a predictable fracture pattern and smooth surface upon breakage. The joint with the obsidian samples exhibited the highest mean break force among all of the lithic raw materials at 130 N per cm²; it also had the highest median at 126 N per cm^2. This outcome is likely due to the exceptionally smooth fracture surface of obsidian, which provides an even and regular area for adhesive application. In contrast, dolerite, an igneous rock with a holocrystalline structure formed from slower magma cooling had one of the lowest results. The holocrystalline structure in dolerite results in a degree of unpredictability in its fracture behaviour. This structural characteristic also leads to the development of a coarser textured surface, attributed to the intergranular fracture pattern. When considering the mechanical adhesion theory, the coarser surface texture of dolerite which adds to the overall surface area, would seemingly contribute to a stronger joint [29]. However, a contrasting result was observed, this sample showed a mean break force of 59.9 N per cm² and an identical median observably lower than that of obsidian. These results could in part be attributed to the challenging irregular topography of dolerite. This surface irregularity hampered the parallel placement of the substrates, preventing axial pressure from being applied. As a result, this situation may have resulted in improperly aligned joints that received primarily bending forces. This mechanism most likely contributes to the lower mean force observed in dolerite specimens.

Table 5. Statistical information of experimental phase 2 in N per cm^2.

	Dolerite	**Flint**	**Obsidian**	**Quartz**	**Quartzite**
N	12	12	12	12	12
Missing	0	0	0	0	0
Mean	59.9	67.1	130	52.2	77.1

Median	59.9	53.0	126	42.8	73.3
Coefficient Variation	34.9	44.4	57.6	43.9	39.9
Minimum	29.1	38.3	31.3	30.4	35.1
Maximum	96.9	127	230	99.5	138

Quartzite is a metamorphosized sandstone and consists of recrystallized quartz. [30]. The size of quartz crystals within quartzite, as well as the presence of cement, are dependent on the conditions under which the rock was formed. Furthermore, the inherent nature of quartzite influences its fracture pattern, enabling fractures to occur both between and through the quartz crystals. [31]. Quartzite exhibited the second-highest mean break force of the joint at 77.1 N per cm² as well as the second-highest median at 73.3 N per cm^2. The irregular fracture plane and coarse surface texture once again posed challenges in achieving axial pressure.

The final test focused on vein quartz pieces, a common mineral present in various rock types. Vein quartz forms from silica-rich fluids infiltrating existing cavities. The crystalline formation of quartz is influenced by factors such as cooling rate and pressure. These factors often result in vein quartz that is not homogenous but has internal flaws and crystalline structural weaknesses, which influence its fracture pattern and knappability [32]. The vein quartz samples exhibited the lowest mean break force of the joints at 52.2 N per cm² and the lowest median at 42.8 N per cm^2. This result could be attributed to both the morphology limitations affecting joint design and axial pressure, as well as the smooth surface that hindered adhesion.

The second phase aimed to understand how different rock types affect adhesive joints. While this goal was partly met, the results were not as clear as expected. The tests showed how various types of rock—flint, obsidian, dolerite, quartzite, and vein quartz—behave when used in joints. However, the knapping process created uneven surfaces and fracture patterns, making it hard to evaluate the true impact of the rock types. Although each rock type had different bond strengths, the irregular surfaces from knapping made it difficult to align joints and apply pressure properly. The uneven surfaces and non-linear forces encountered with knapped rocks complicated the ability to isolate the effect of the rock type alone.

4. Discussion

The goal of this study was to investigate how different rock types might influence gluing properties. However, the impact of knapping on these properties was underestimated. During the first phase, it became clear that multiple factors contribute to joint strength. In the second phase, it was evident that the test bench was inadequate for fully assessing the impact of rock types, as the required angle of force could not be replicated with the knapped lithics. Preliminary findings suggest there may be differences in how the adhesive interacts with various rocks. For example, both flint and obsidian have relatively straight profiles, but flint exhibited a much lower mean force per centimetre. However, when a Games-Howell post hoc test was conducted, it showed that flint and obsidian were not statistically different (Table 6).

Table 6. Games-Howell posthoc Test results, comparing standardised substrates (glass) from experimental phase 1 and joints using unstandardised substrates tested in experimental phase 2.

		Dolerite	Flint	Obsidian	Quartz	Quartzite
Dolerite	p-value	—	0.981	0.071	0.953	0.606
Flint	p-value		—	0.135	0.742	0.963
Obsidian	p-value			—	0.040	0.270
Quartz	p-value				—	0.259
Quartzite	p-value					—

An alternative approach could involve using laser-cut blanks to standardize the substrates. However, this would not reflect the forces experienced by archaeological tools, defeating the purpose of the study. This raises the broader question of whether bench tests are appropriate for capturing the nature of archaeological adhesives, as they struggle to account for real-life angles and dynamics. Moreover, the number of variables that influence glue performance is high, which is once more confirmed by the results of phase 1.

How do our results compare to other mechanical studies on different adhesive recipes? The adhesive tested in this study (a mixture of beeswax and resin) demonstrated relatively low shear strength, even when applied to standardized, straight substrates and tested under axial force. Additionally, this adhesive was highly sensitive to environmental factors such as temperature, as observed in Phase 1. This sensitivity is not unique to this particular recipe; many other resin-based adhesives exhibit similar properties. Test involving tar and gum have also monitored temperature to insure success (see suppl table 1).

By examining the results of the multiple mechanical tests on various adhesive recipes, we can gain a broader understanding of the characteristics of archaeological adhesives. Mechanical tests have provided valuable insights and when the data are reviewed (see Table 7), it becomes evident that shear strength is generally not a strong feature of most archaeological adhesives when evaluated using bench tests. Our findings align with those of other studies, which also indicate that adhesives are vulnerable to temperature changes (see Suppl. Table 2).

Table 7. This table summarises the results of mechanical tests done by other researchers on various archaeological adhesives in N per cm^2. The results are grouped by the type of adhesives used in the test. All other information regarding the test can be found in Tables S3 and S4.

Adhesive type	Average (N per cm^2)	Average CV (%)	Max mean (N per cm^2)	Specifics of maximum mean values per group
Animal glue	159	38.8	270.5	Fish glue [24]
Tree Gum	31	18.5	518	Gum Arabic [2]
Plant exudes	22.7	43	48.2	Ficus [9]
Resin mixtures	152	25	349	Resin based mixture: Pine Rosin 3.5: Beeswax1.5: Ochre1 [2]
Tar	69.7	32.7	190	Birch tar with condensation method [28]
Bitumen	16.4	42.3	149	Air-dried [14]

Thus, based on previous studies and the study conducted here, archaeological adhesives show two consistent characteristics: 1) they do not exhibit high shear strength, and 2) they are vulnerable to weathering, particularly temperature fluctuations and moisture. The ability to withstand 700 N per cm^2 force and resist environmental factors are properties typical of structural adhesives, which are designed for strength and durability [29] . In many prehistoric hafting systems, however, adhesives seem to play a supportive role, stabilising or sealing the binding, which aligns with the characteristics of non-structural adhesives [29] . Prehistoric adhesives should thus not be treated as structural adhesives where joint strength would be the key factor guiding their production and use. This challenges the role we want to attribute to mechanical testing when studying prehistoric adhesives.

While the distinction between structural and non-structural adhesives does not negate our existing knowledge of prehistoric adhesives, it does significantly influence our understanding of how they were used. Modern glues, for instance, are selected and applied based on their specific properties: fast-drying, rigid adhesives are unsuitable for tasks requiring flexibility, and slow-drying, mouldable glues are applied differently than their hardening counterparts. This distinction is crucial in experimental archaeology, particularly when replicating the attachment of stone tools to hafts for projectiles or other uses. For example, if the adhesive tested in this study were applied as a thin, even layer between a stone tool and its haft, it might not yield much success. However, this specific resin beeswax mixture excels in moulding applications, as it can be shaped during its cooling process to create transitions and encase components. Ethnographic examples, demonstrate this practice as illustrated in Figure 1 as well as ethnographic studies by Wadley [33], Weedman [34] and Sahle

[35] where the adhesive is used in a supporting role. Unlike the axial pressures replicated in mechanical experiments, real-life hafts, whether from ethnoarchaeological studies or experimental studies with the four basic hafting types outlined by Barham [17], experience a broader spectrum of forces that are not accurately reflected in mechanical testing. Some research indicates that cleft hafts and L-notch hafts may experience similar forces to those tested in bench tests [2,18,25]. However, in the case of cleft hafts, the lithic insert is positioned into a slot and secured by bindings, adhesives [17] or both, and the adhesive's role is not as critical to the success of the hafting as it is in lap shear joints. In both the L-notch and cleft hafting arrangements, the role of adhesives does not compare to lap shear joints and other properties like moisture resistance, moulding and gap-filling properties might be more desired in these designs, as also demonstrated in other studies (Tydgadt & Rots accepted). This does not imply that all archaeological adhesives behave this way, but highlights that shear strength might not be the primary factor that sets different adhesive recipes apart from each other.

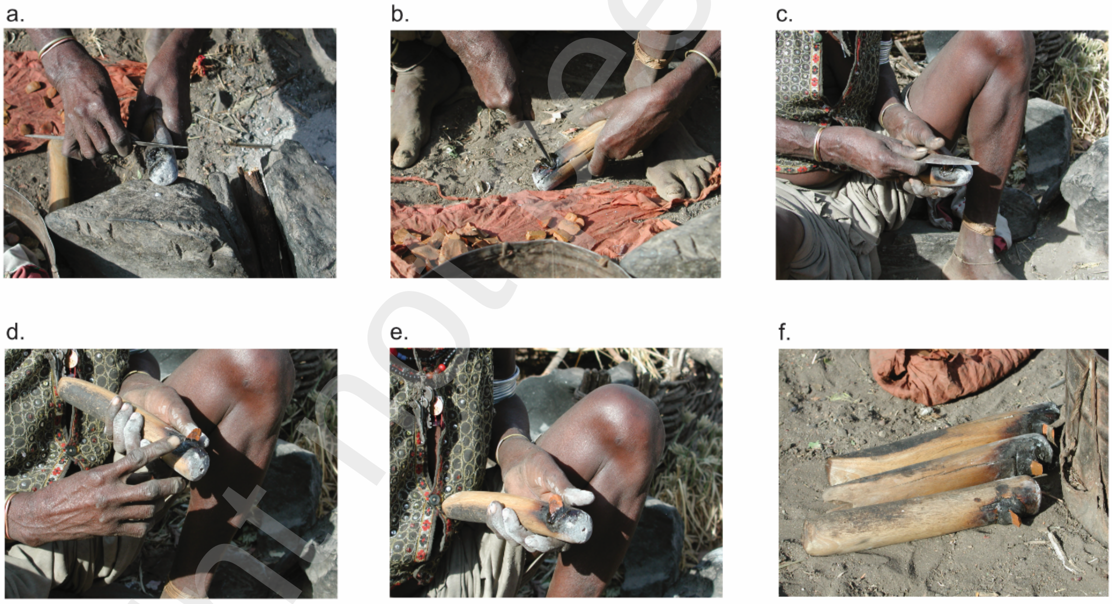

Figure. 1. The on-site hafting process of a stone scraper done by Konso hideworkers in Southern Ethiopia, during a scraping event in the village of Gocha. Pictures by Veerle Rots. (a) Re-positioning the resin that already served in a previous hafting and use cycle after heating the extremity of the handle in hot ashes of a fire (with incidental addition of charcoal into the mixture). (b) Creating a hole within the resin for the scraper. (c) Pushing the scraper into the resin cavity. (d) Moulding the hot resin into the desired shape. (e) Smoothing the edges of the resin. (f) The final scrapers with lithic inserts are held in place by resin.

Other experimental studies have also highlighted additional features that contribute to the success of an adhesive in various tasks. For instance, Wadley [5] tested different adhesive recipes and concluded some might have been chosen for specific functions above others, while Tydgadt and Rots [36] identified moulding as a valuable quality for attaching barbs to projectiles. The detachment of barbs upon impact has been a subject of discussion for some time [37] , with certain sources [38] proposing that this phenomenon may serve an intentional function by promoting increased haemorrhage as the animal continues to move. These more actualised experiments have brought to light the importance of other adhesive properties, such as moldability, workability, and controlled failure under stress. These qualities may have made certain adhesives particularly suitable for specific hafting applications, where flexibility and adaptability were more critical than shear strength. Archaeological adhesives are frequently discussed in debates about cognition due to the analogical reasoning and effort involved in their production. While this connection is not disputed, some theories take it further by proposing that the high shear strength of adhesives like Podocarpus tar (although see supplementary table S4) may have motivated Middle Stone Age foragers to invest significant time and effort in their manufacture [9] . It has also been suggested that properties such as strength and stiffness were highly valued, as stronger adhesives could withstand greater working pressures, potentially justifying their more labour-intensive production [23,26]. However, the idea that prehistoric humans deliberately modified techniques to prioritize adhesive strength is intriguing but may be premature. Strength might not always have been the primary quality sought, suggesting a more nuanced approach to understanding the choices made in adhesive production and use.

Conclusion

In our pursuit to bridge the gap in mechanical testing, we turned to knapped lithics, to more closely simulate archaeological scenarios. Although the second experimental phase encountered challenges due to the geometric variability of the knapped lithics, preventing a definitive evaluation of the influence of rock types on joint strength, the results highlighted several key factors for advancing our understanding of archaeological adhesives. Archaeological adhesives are not particularly strong in terms of shear strength and many variables intervene that cannot all be controlled in real-life situations. This implies that one may search in vain for the ideal adhesive recipes or production methods to improve strength or success rates, because the qualities depend mostly on how the adhesives are applied, environmental conditions and what tool uses are considered. Reframing them as non-structural means that shear strength may not have been their primary or most valued property. Instead, other characteristics—such as the moldability of resin, beeswax, or tree gum, or the waterproofing properties of tar—may have been critical for specific hafting scenarios. Thanks to previous mechanical testing conducted on various adhesive recipes, we have a good understanding of the shear strength of prehistoric adhesives. Building on this we can now explore the other qualities in which non-structural adhesives excel to improve insight in technological choices. Investigating these properties would provide deeper insights into the functional uses of prehistoric glues and inform experimental studies aiming to replicate their applications in ancient contexts. Such evaluations hold the potential to advance our understanding of adhesive technologies during the Middle Stone Age and Middle Paleolithic, shedding light on their broader implications for innovation and adaptation in human prehistory.

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