Experiments in *Cuir Bouilli*: Practical Trials of Medieval Leathercraft

by

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Abstract

This thesis pursues an experimental investigation of *cuir bouilli*, a particular form of hardened leather used as armor in medieval Europe. In this exploration, I have produced a sample group of 30 distinct varieties of *cuir bouilli*. These samples represent the most commonly theorized and scientifically grounded production methods of this historic medium. Using a series of armor specific tests, broadly encapsulating the abuse of arrow fire, blunt force trauma, and slashing, I have measured the performance of each *cuir bouilli* sample. The data gathered from these tests can be used to infer physical properties about each sample, revealing the essential effects of each hardening method. Moreover, these tests indicate how *cuir bouilli* might have functioned in actual armor use. They demonstrate strengths and weaknesses of each variety, offering reasons for their eventual abandonment in certain contexts and the roles they might have continued to play in others. In this way, the position occupied by *cuir bouilli* in the development of bodily protection in military contexts is better understood.
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Chapter 1: Theory of Experimental Archaeology

Archaeology is a discipline that studies human history, as understood from surviving material remains. Traditional varieties of culture-historical and ethnoarchaeology excel at examining material cultural in its recovered context. They concern themselves with the discovery and excavation of sites, analysis and arrangement of data, and dating to draw inferences about a culture and reconstruct our understanding of them based upon these deductions. In the second half of the 20th-century, processual archaeology (formerly new archaeology) has championed the application of the scientific method to archaeological questions. In the previous twenty years especially, field archaeology has become highly interdisciplinary utilizing increasingly sophisticated methods of data analysis, geophysical surveys, and dating to dramatically magnify the potential for discovery with any site or given object. Artifacts provide a static record of the past in the present. While the arrangement of these artifacts is the primary goal of culture-historical archaeology, this is not the end goal of modern archaeology practice. Processual archaeology seeks to understand the dynamics of past societies how they functioned and developed (Johnson 2010: 51). It asserts that more can be understood from these artifacts than mere physicality.

All archaeological statements about the past are inevitably made in the present. These statements rely upon analogies; “the use of information derived from one contest, in this case usually the present, to explain data found in another context, in this case the past” (Johnson 2010: 50). Any archaeological statement makes an
assumption that events that occurred in the past are analogous to events in the present, the position we must approach them from. These assumptions function as a middle-range between the fixed physical record and dynamics of the past. They guide archaeologists, allowing them to construct arguments about archaeological material that connect the artifacts themselves to the human or natural processes that produced them (Raab 1984).

Of course, our understanding of the past is limited. Past activity patterns can never be observed directly. They leave only material remains as indirect evidence of their occurrence. However, by looking at comparable activities in the present, “archaeologists can make a detailed and accurate record of how particular activities or systems of activities give rise to particular patterns of archaeological debris” (Johnson 2010: 53). These studies function as analogies, relying upon the assumption that past processes might resemble those in the present. These carefully observed modern models can be used to inform our understanding of past processes. Thus, actualized studies taking place here and now might be essential to understanding past patterns of behavior.

*Experimental archaeology* has grown out of middle-range theory as an exciting theoretical and methodological position from which to attack archaeological mysteries. It provides a direct, actualized approach to studying materials culture. Culture-historical models are limited when a problem remains that cannot be answered using available archaeological evidence. In these cases, experimental archaeology might be of use. As Toni Carrell describes the profile, “they represent problems in interpreting archaeological material arising as a result of poor artifact
preservation, incomplete survival, loss of understanding of original purpose, and doubts about presumed function or performance" (Carrell 1992: 6). While the sub-discipline was born from antiquarian interests in replication, it has matured to become a systematic method for understanding problems that do not present themselves well in the archaeological record (Coles 1979: 161). Thus, the middle-range approach of experimental archaeology provides a unique avenue for expanding our knowledge of cuir bouilli. Using modern research procedures and perspectives, I seek to produce analogs of ancient methods of leather craft, as used for leather armor, ultimately testing their performance as a defensive material. In the sections that follow, the particular theoretical approach offered by experimental archaeology will be unpacked as a relevant and viable means for renewing our understanding of hardened leather. Throughout, the specific considerations that have been made for my study and parameters for a successful project will be outlined.

As following chapters will explore, cuir bouilli is a medium whose true form and nature continues to elude archaeologists, conservationists, and artists alike. Despite what appears to be a great body of evidence supporting the use of hardened cuir bouilli leather as defensive armor, archaeological artifacts able to confirm such use are limited to only a handful of surviving objects. Nevertheless, compounding evidence of visual images, etymological origins, and artisanal offshoots make a compelling case for its existence and use in this way. The uncertainty that surrounds cuir bouilli has inspired numerous previous investigations. Scholars such as Waterer (1981), Lingwood (2013), Cameron (2000), and others have attempted to clarify the definition of the term with limited success. These scholars have made explorations
into the production of hardened leather in an attempt to demonstrate the viability of certain methods. Over the years, contrasting opinions that champion specific procedures have emerged. Disagreement concerning nearly all aspects of the *cuir bouilli* production process exists, notably about the functional effect of greater than shrinkage temperature conditions on vegetable tanned leather.\(^1\) The possibility of a beeswax or pitch medium as a stuffing agent is likewise debated. Unfortunately, these past studies have been hindered by uncontrolled, qualitative methods unable to adequately express the essential characteristics of *cuir bouilli*. Thus, Carrell proposes that, “when theorizing has gone as far as it can and the desire and opportunity to tackle the problem from another avenue is strong, empirical evaluation, through experimental archaeology, is a viable research tool” (Carrell 1992: 9). It is with this summon that I define my own experiment, to measure the effectiveness of *cuir bouilli* leather hardening treatments as determined by armor specific tests and challenges.

Once all issues surrounding *cuir bouilli* are enumerated, the experimental design process can begin, conceived within a greater archaeological context (Kelterborn 2005). By this, I mean to define the scope of my project, which addresses the particular methods of hardened leather production that appear to have prevailed primarily during the 11th to 14th-centuries CE in post-conquest England and southern Italy. As I will explore in Chapter 3, both of these regions appear to have been experimenting extensively with hardened leather armor during the transformative

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\(^1\) This position is most prominently disagreed upon by John Waterer (1981) and Rex Lingwood (1980). Waterer implores the use of greater than shrinkage temperature conditions for either water immersion or baking -- he puts a cap at 55ºC as the greatest possible temperature that leather can be worked with for molding and hardening. In contrast, Lingwood has found success in his artistic studies using leather that has been exposed to far greater temperatures, including boiling.
period of en route to metal plate armor. Bearing distinct regional typologies of shrunken or waxed *cuir bouilli*, the potential armor capabilities of each technique will be assessed. As Ferguson recognizes, “experimental archaeology is preferred for isolating the effects and relationships of small sets of related variables” (Ferguson 2010: 2). When applied to the problem of *cuir bouilli* production and use, it can be used to isolate the effects of each treatment procedure on a standardized sample of vegetable tanned cowhide.

Experimental archaeology has frequently been applied to craft or artisanal industries. It is “designed to look at ancient man as an inventor, a technician, a craftsman, an artist, and a human being. By reproducing his actions archaeologists can better understand not only his technical abilities but also his reasons for choosing one course of action rather than another” (Coles 1979: 2). The actualized approach of experimental archaeology seeks to reveal nuances and subtleties in the material or process that could not be known otherwise. Yet any skill, especially one that requires a degree of dexterity or timing, can only be mastered through experience. It “makes the point that even a simple implement of stone requires not only an understanding of the material and its theoretical properties, but an experience born only of tradition or long experimentation” (Coles 1979: 9). In the field of *cuir bouilli*, there can be no doubt that artisans such as Rex Lingwood are our closest modern analogs to skilled medieval leatherworkers. Lingwood uses his discerning eye and experience working with leather to achieve success with the medium. Skills such as these, however, take many years of experience to cultivate. Moreover, previous projects have revealed that, “in almost all experiments, the most difficult variable for which to control is the
human user” (Ferguson 2010: 5). It must be recognized that the people archaeologists seek to study were very likely more skilled with the medium.

Experimental archaeology recognizes a distinction between *controlled laboratory experiments*, “characterized by their replicability and tight control of very few variables,” and *field experiments* which, “relax control of variables to more closely replicate possible prehistoric situations” (Ferguson 2010: 4). In an attempt to isolate the effects of various treatments methods, namely boiling, baking, and waxing, my experiment is decidedly laboratory based. To minimize the impact of my inexperience with the material, strict prescriptions are be made and adhered to. It is with this in mind that I have constructed my sample group. Each treatment process is defined particular variables which when modulated reveal the essential effects of each treatment. Throughout this 30-sample group, all four defining variables are combined at various stages to understand how different treatments might interact.

Obviously, with a limited sample group of only 30, every possibility for the production of *cuir bouilli* cannot be considered. By isolating each variable, the idiosyncratic characteristics of each piece of leather are exchanged for greater scientific control. I seek to “describe universal properties of common materials and apply to the same archaeological material regardless of cultural setting.” (Ferguson 2010: 5). My experiment seeks to objectively consider variables pertinent to the *cuir bouilli* production process. While the techniques I explore were certainly inspired by regions that seem to have used them most extensively, the basic physical and chemical principles might be further reaching. The fact that *cuir bouilli* is best documented in England and Italy does not preclude its use elsewhere. The essential
material effects of boiling or waxing leather might be understood as relevant to their potential use in any locality. *Cuir bouilli* might have been possible anywhere vegetable tanned leathers constituted a substantial part of the material culture.

Coles recognizes three levels which experimental archaeology projects can be broadly grouped into. The lowest level is simulation, which seeks to “[make] a copy of an original artifact with attention only paid to its visual appearance for display purposes” (Coles 1979: 36). These experiments are limited in their actual historical or scientific authenticity, but may provide stimulating educational opportunities.²

The second level Coles identifies is “concerned with testing for the processes and production methods used in the past” (Coles 1979: 38). Within my sample group, I attempt to verify the viability of different production techniques. This process seeks to produce historically inspired analogous samples, demonstrating whether such techniques could conceivably have been used to produce hardened leather armor of a general typology. Due to the rigidity of my production methods, necessary to support objective analysis of each variable, a historical artisan might have been able to produce materials which were of varying or superior quality. Nevertheless, the parameters I have outline for my own *cuir bouilli* production should be capable of signifying the general trends in associated with each method. Should a favorable quality arise, it indicates the direction further experimental research might continue, building upon the discoveries I’ve made here.

Finally, Coles recognizes a third level of experiment, “concerned with the function of the artifact, that is the use or uses to which the object is presumed to have

² While replicas are not tested for function or purpose, they may be suitable as museum displays or classroom tools. Reconstructions of ancient monuments or structures are especially capable of inspiring public interest in the appreciation and further studying of the past.
been put” (Coles 1979: 39). I endeavor to measure the effectiveness of each produced *cuir bouilli* sample as defensive armor. Using simulated armor tests, the defensive qualities of each sample are quantified. Thus, material differences between samples are substantiated by empirical data that reflects these characteristics. By understanding how particular samples or recipes resist attacks, the practical application of *cuir bouilli* can be assessed. Thus, the role of *cuir bouilli* as defensive armor can be explored and its place within the development of metal plate armor can be better recognized.

With my mission defined, I must emphasize the ephemeral nature of both leather as an organic material, and artisanal craft production as a fragile tradition of knowledge. Due to the organic quality of leather, its preservation for any extended period of time faces many possible complications. As other conservationists have explored, leather is susceptible to a multitude of bacteria, fungi, and chemical imbalances which would seek to destroy the physical quality of the hide. The vegetable tanning process, effective as it may be, cannot preserve a hide without regular attention. When discarded or neglected, these agents of decay quickly destroy the would-be archaeological evidence. The great lack of surviving *cuir bouilli* armor examples can be largely attributed to this natural limitation. Those artifacts we retain tend to be from later dates or are isolated examples.

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3 Conservationists especially are aware of the chemical and mechanical processes which might compromise the structural integrity of a hide, including heat, water, acidity, and even light (Florian 2006). Consequently, modern conservation of archaeological leather materials utilizes specialized chemical principles to combat further decay and prolong archival life (Spriggs et al. 2006).

4 English *cuir bouilli* blackjacks and bombards continued to be produced up until at least the 18th century. During this time, it is believed that few modifications were made to their form and composition, providing possible models for study (Baker 1921). Otherwise, a Bronze Age leather
Individual and collective knowledge of an artisanal craft industry are equally susceptible to the erosive power of time. In the decades following the introduction of modern industrial production, or any technology that supersedes another, “skills that were once highly prized lose their economic value and disappear from the workshop. Too many artisans go to their graves without an opportunity to pass on the ‘mystery’ of their crafts” (Malone 2000: 85). Proficiency in such crafts would ordinarily have followed an apprentice-tutor model. Without the need to continue traditional production methods, skilled crafts can disappear even within a generation. As a result, cuir bouilli crafting methods are conspicuously absent from medieval craft records. Bodies of knowledge can in fact disappear quite suddenly from the historical record if neglected, as it seems cuir bouilli has been.

As Cole so aptly puts it, “the discipline of archaeology, as a science and an art, is bounded by the amount and variety of the evidence available, and it is shaped by the measures adopted to handle and interpret this evidence” (Coles 1979: 32). In lack of copious artifacts from which to approach the subject of cuir bouilli, experimental archaeology provides the opportunity to contribute to this body of knowledge. Whenever possible throughout my project, I will seek to make these considerations self-evident. Nonetheless, the specific adaptations, analogs, and assumptions I have made will be constantly explicated as agents to this process, asserting the authenticity of methods and data collected.

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5 Shield provides one of the only additional relics of this historical technology. This evidence will be discussed at length in Chapter 3.

5 While medieval tanning practices have were documented, no such records exist for the production of cuir bouilli. With a precedent set by Vitruvius, whose contribution to our knowledge of Roman crafts cannot be understated, treatises such as 12th-century De Diversis Artibus were in fact being produced. However, anything specific to the cuir bouilli crafting process seems to be overlooked.
Chapter 2: a Short History of Leather and Armor

Leather has been a staple of human material culture for millennia, used by virtually every society across the globe in a staggering assortment of applications. However, the origins of this now ordinary material are shrouded in uncertainty. Leather and other skin products are organic substances and prone to rapid deterioration when abandoned or mistreated. As such, limited examples of ancient hide survive in the archaeological record for analysis today. What is known, however, is that leather and the processing of animal hides is a prehistoric industry, practiced in a primitive form by early hominids and ancestors of modern humans. In lack of substantial leather artifacts as direct archaeological evidence for ancient hide processing, these techniques require alternate means of analysis to be understood. I seek here to provide a broad picture of the development of the leather and hide industry from its earliest origins, through the industrial revolution. The developments explored here will provide the necessary background for understanding the place of cuir bouilli within a broader canon of leather goods and artifacts. Moreover, it will realize the specific conditions and circumstances in which cuir bouilli could have occurred and constituted a significant aspect of a material culture. As I will explain, the regions and time periods in which cuir bouilli potential existed are not necessarily limited to those explored most thoroughly within the confines of this paper.

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6 My report terminates at the industrial revolution due to the immense reorganization of leather working industries during this time. Following the industrial revolution, suppliers, tanners, and other associated tradesman ceased to function in a model comparable to earlier centuries (Thomson 2006: Manufacture of Leather 73). This reorganization is no longer relevant to my thesis.
Early Hominin Hide Use

The earliest identifiable use of hide products can be traced as far back as Australopithecus habilis, also known as Homo habilis (Tobias 1965; Thomson 2006: Manufacture of Leather 66). This early hominin species, an ancient predecessor in the human evolutionary lineage, is most notable for its pioneering use of stone tool technology some two million years ago. Lithic tools provided the necessary mechanical advantage to efficiently process animals and make most extensive use of their offerings. With these resources now available for exploitation, hide processing developed as a common and necessary facet of prehistoric material culture.

Prehistoric hide use can be confirmed from the wear analysis of stone tools. Studies have verified that pieces of raw hide were used to grip the sharp stone tools which they depended on, minimizing wear on hands before hafting technology became common. This simple use of untanned hide was likely one of its most ancient applications, predating more complex hide processing methods. Early stages of hide processing are suggested by microscopic edge analysis of stone scrapers used to remove the excess flesh from hides. These patterns of wear have been replicated

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7 The process and mechanisms of human evolution are not within the scope of my paper, however, the pioneering use of tools by early hominins represents an essential step in the trajectory of leather development and use. For a more complete picture of human evolution, as known through archaeological evidence, Ian Tattersal’s The Fossil Trail (Oxford University Press 2008) is a substantial work.

8 Hafting technologies have been the subject of a variety of experimental archaeology projects, examining the particular ways stone tools might have been handled. Patches of raw hide might have been used to grip the sharp edges of tools. Strips of raw hide could also have been used to lash a stone blade to a handle (Rots 2005). See [Figure 2.1] for an illustration of this usage.

9 Microwear analysis of stone tools is in fact one of the most extensive subjects of study in experimental archaeology. Even in the earliest years of the subdiscipline, attempts were being made to document and reinterpret the production of flaked arrowheads and blades. Today, full guides to
in a number of experimental archaeology projects which demonstrate how these blades would have been used most effectively. These studies confirm that early hide processing was indeed a multi-stage process, with raw hides subjected to many episodes of scraping. This was first performed while the hide was fresh and rich with natural moisture. Scrapers used to work wet hide are identifiable by their distinct edge polish, caused by repeated abrasion with moist hide. After initial defleshing of the hide, the hide could be stretched using frames and dried in the sun. Dry hides were then scraped by hand, breaking down the tough bundles of collagen fibers and refining the surface to a smoother finish. Scrapers used to work dried hide are characterized by a rougher edge polish, caused by the more abrasive quality of dry collagen fibers, and frequent resharpenings needed to effectively work this tough material [Figure 2.2].

Prehistoric Development of Tanning Methods

Sun drying and oil tanning were likely used to preserve the earliest processed hides. Oil tanning could be achieved by working fatty acids into the collagen network of the hide. Modern experimental methods have demonstrated that natural materials such as animal brains, liver, and egg yolk are all effective means of preserving this fibrous structure (Coles 1979: 198). These agents would have been applied between designing experimental research in lithic technologies exist, demonstrating the strides and maturation or this particular specialization (Bradbury et al. 2010).

In Rots’ study of stone tool technology, She attempts to replicate the wear patterns characteristic of prehistoric stone tools using primitive hide processing methods. The findings demonstrate that steps such as defleshing and unhairing hides were indeed practiced as part of this process, leaving distinguishable wear patterns that confirm their use (Rots 2005).
stages of scraping and sun drying, thoroughly massaged into the fiber network by hand. However, because oil tanning is achieved primarily through surface manipulation, its usefulness is generally limited to thinner hides, able to be fully penetrated by the massaged oils. As elaborated in Chapter 4, oil tanned hides would not be recognized as leather by today's standards. They lack the chemical manipulation that characterized true tanning methods, prolonging their life markedly.\(^\text{11}\) Oil tanning is still used today in specialty hide production such as buckskin.

It also seems probable that simple forms of clothing would have developed from available hide resources. These early attempts to clothe the body were likely prompted by thermal necessity, using hides as a form of simple, draped clothing to insulate the body from harsh weather conditions.\(^\text{12}\) For the average human, the threshold of cold tolerance occurs at \(-1^\circ\text{C}\), the lower limit before hypothermia sets in (Gilling 2007: 102). In order to survive in more extreme temperatures, pelts became an essential aspect of material culture, taking advantage of the immense natural insulating properties of animal furs. The methods for manufacturing and processing pelts are fraught with their own technical nuances, largely dependent upon the type

\(^{11}\) Oil tanning processes have been explored in depth, at an archaeological and chemical level, in previous studies. However, hides preserved using this process are generally unstable unfit for cuir bouilli production. Thus, they do not constitute a focus of my research. For more information on oil tanning (Stambolov 1969) and (Covington 2006) provide a sound foundation.

\(^{12}\) Gilling makes a distinction between simple and complex clothing in human development. He classifies simple clothing as only a single layer, draped loosely over the body and displaying little evidence of stitching, mending, or other modification. Due to the loose fit of simple clothing, if provides poor wind protection, yet offers appreciable insulation in still air. In contrast, complex clothing consists of more than one layer. It is more sophisticated in manufacture, cut and stitched to fit the body. As a result, complex clothing offers insulating properties and wind protection (Gilling 2007).
of fur being processed.\textsuperscript{13} Furs have commonly been understood as luxury goods, especially in more temperate climates where they are not of absolute necessity. These developments in clothing technology were sure to occur at different times across the globe, responding most directly to weather that would be otherwise inhospitable. Upper Paleolithic rock paintings dated to 35,000BC, seem to depict hide garments, demonstrating their longstanding use where archaeological evidence cannot provide [Figure 2.3] (Thomson 2006: 67; Waterer 1981: viii).

Ancient dwellings and other structures also made extensive use of hide as a building material. Draped and secured over timber frames, hides were used to erect walls and draw early designations of inside and outside space. Due to the simplicity of this building technique, the entire structure can be deconstructed and transported with relative ease, making it perfect for early hunter-gatherer societies, constantly on the move in search of the resource rich environments.\textsuperscript{14} These methods of construction can still be observed among North American First Nations tribes. With fires built within these hide walled dwellings, the smoke wafting through the air would gradually dry and cure the hides. Over time, this process would have altered the chemical composition of the hides, making them more supple, durable, and long lasting. It has been speculated that the interaction of smoke and hide in this style of dwelling might have spurred the development of more sophisticated tanning

\textsuperscript{13} While tanning of most mammalian skins is follow nearly identical procedures, specialty hide products such as furs, pelts, and more exotic species require idiosyncratic tanning methods (Stambolov 1969; Graemer 2006).

\textsuperscript{14} Significant studies of early human settlement patterns and structures have been conducted by previous scholars. The use of hides as an essential building material by prehistoric peoples is discussed at length by Klein (1969).
processes such as vegetable tanning, described in depth in later chapters. Smoke tanning is considered the earliest form of tanning and thought to have originated in Mongolia where dung was burned as a tanning agent (Stambolov 1969: 15). If a prehistoric human were able to recognize this preservation effect and connect it to the smoke below, rich with vegetable tannins from the burnt organic material, the origins of the vegetable tanning process might be at hand (Thomson 2006: Manufacture of Leather 66). Thus, a combination of smoke and oil tanning likely typified most prehistoric leather production. It should be noted that these attempts to preserve and manipulate hide, were one of man’s earliest industrial endeavors and manufacturing processes. Apart from the production of stone tools, few other activities would have offered a greater utility value and contribution to observable material culture.

**Leather Industry in the Ancient and Medieval Past**

The precise trajectory of tanning and hide processing by prehistoric cultures remains unresolved even today. Since each locality might have developed these techniques at different times, assigning a hard timeline is difficult. However, ancient civilizations in Near East offer substantial evidence of vegetable tanning, the preservation technique that would come to define modern leather production. Egyptian tombs depict hide production and use as far back as 2000BC in a number of artistic images [Figure 2.4]. Similarly, Mesopotamian cultures from 1500BC show ample evidence of vegetable tanning industries.\(^\text{15}\)

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\(^{15}\) Ronald Reed has aggregated much of this evidence to construct tables that summarize the confirmed hide production processes of these ancient cultures. He recognizes that they must not have originated
While the prehistoric and ancient tanning processes are rife with uncertainty and variation, by the time of the Roman Empire, vegetable tanning was a well-established industry. Excavations of Pompeii have yielded evidence for vegetable tanning industries, including fifteen pits used to ferment hides in tanning liquors (Faber 1938). While these pits preserve tanning the infrastructure, industrial waste might also be used to reconstruct tanning operations. Leather scraps and trimmings from Roman London bear distinct inscriptions [Figure 2.5]. Stampings and other markings on these scraps indicate personal names, perhaps of the tanners themselves (Rhodes 1987: 174). This might reveal that the tanning industries of Roman London were shared facilities. The presence of multiple names and types of markings added at progressing stages of the tanning process could have been used to signify ownership of an individual hide, otherwise indistinguishable from others in the tanning pits. These inscriptions might indicate that by this time some standardized or relative measures of quality had been established. The flourish of activity suggests that tanning industries in Roman London were prominent during the 1st and 2nd-centuries AD, especially when compared to the relative absence of tanners marks at other British sites (Rhodes 1987: p.176). Although it is unknown whether raw hides used for leather production in Roman Britain were sourced locally or imported, the region clearly expressed a high demand for leather products and had the infrastructure to perform most vegetable tanning locally.

during these centuries, already the product of a length period of discovery. Nevertheless, these cultures produce the earliest certifiable evidence of vegetable tanning operations (Reed 1972: 86).
Leather production in the middle ages was more thoroughly documented, giving us a clearer picture of the relationships between the farmer or producer of cattle, butcher, tanner, currier, and eventual craftsmen.\textsuperscript{16} It is generally understood that the tanner’s primary supplier of hides was the butcher, who was responsible for skinning and processing the animal carcass. Flayed hides were sold with the feet or hooves and associated bones still intact (Thomson 1998: 4). Hides generally did not arrive to the tanner in a fresh, newly skinned state. Rather, most hides were cured or preserved with salt, especially when the hides were imported and not locally produced (Thomson 1998: 4). Preparing the hides for tanning always begun with a thorough cleaning and removal of the attached limbs. As a result, tanning workshops can often be identified by their characteristic bone waste.\textsuperscript{17} Hides were generally immersed in water to remove blood, dirt, and other fouling accumulated and to wash away the salty solutions used to preserve the hide during transport. This was often performed by leaving the hides in a river or stream, letting the running water do most of the mechanical work [Figure 2.6]. This could be accelerated by beating the hide with mallets or stomping underfoot and also served to rehydrate the hide (Thomson, 2006: \textit{Manufacture of Leather} 69). For this reason, tanning workshops were often

\textsuperscript{16} The trajectory of vegetable tanning development in specific regions has been the subject of other scholarly works which account for the natural and historical circumstances that promoted the adoption of these methods around the globe (Stambolov 1969: 16), and in Europe specifically (Cameron 2000: 70). I seek here to explore only general trends within this development, though Britain is used as a model.

\textsuperscript{17} It has been suggested that the purpose of leaving feet attached to a hide was to offer an indication of quality about the animal (age, health, etc.) (MacGregor 1998). Analysis of these bone remains associated with medieval tanneries can give an indication of output as well as surrounding agricultural conditions (Wigh 1998).
located in close proximity to substantial waterways, essential for the vast amount of water needed throughout the process (MacGregor 1998).

Once the hides were cleaned to satisfaction, the next step was to remove the hair using limed solutions. Hide were folded and allowed to putrefy slightly only on their outer surface. This loosened the follicles so that the hair could be easily scraped off with a blunt knife [Figure 2.7]. Once unhaired, alkaline solutions of bird droppings and dog dung were used to remove the excess lime and refine grain (Thomson 1981: 164). Hides were then ready for immersion in their first bath of mild tanning liquors, generally the nearly exhausted tanning liquors from the last batch of leather produced.

After some time, hides were moved to their final tanning pits where they remained for a year or longer in some cases. These hides were stacked on top of one another in the tanning pits with alternating layers of vegetable tanning material in between, maximizing exposure throughout [Figure 2.8]. The tanning material used varied according to region. Generally, the most readily available tree material was used; primarily oak in Britain and Central Europe (Thomson 2006: Manufacture of Leather 70; Harvey 1921). During the later medieval period, oak was proclaimed the only legal tanning material for cattle hides (Thomson 1998, p.7). While it is certain that other tanning materials were used on occasion, oak appears to have been recognized as a particularly effective tanning agent. Attempts to enforce oak as a standard of the leather industry might be thought of as early markers of quality and measure for comparing other leathers.
Once hides were fully tanned, the currier performed the remainder of the leather manufacturing process. In a medieval setting, tanner’s and currier’s jobs were separated quite distinctly. While the tanner was responsible for the processes that transformed fragile, raw hides in to durable leather, the currier took on most of the finishing and final preservation of these skins (McGregor 1998: 16; Thomson 1981: 166). After receiving coarse leather from the tanner, a currier trimmed them down to a desired, uniform thickness. This was achieved using a long, slender knife with handles on both ends so that it could be pushed or pulled across the hide. It might even be said that the currier’s knife was the fully realized tool prototyped by the stone bladed scrapers pioneered millennia before [Figure 2.9]. Finally, a currier was responsible for the essential after treatments that prolonged the life of the leather. These included oils and fats to hydrate and waterproof the collagen fibers increasing its pliability and resisting wear (Thomson 2006: Manufacture of Leather 70).

While the infrastructure and organization of the leather industry underwent changes over the millennia as relationships between participants shifted, the basic science of the tanning industry remained relatively static. Tanning methods became more precise, able to deliver concentrated, effective doses of preservative that produced higher quality leather. Vegetable tanning remained the primary means for producing leather from antiquity, through the Industrial Revolution (Thomson 2006: Manufacture of Leather 68). A final leather product, finished by the currier, could

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18 The fundamental chemistry of vegetable tanning will be discussed more thoroughly in Chapter 4: the Science of Leather. Though modern industrial tanning vats bear little surface resemblance to the earthen tanning pits which defined historical leather treatment, the chemical agents at work are alike. Thus, vegetable tanned leather is generalized as a category of material, a crucial assumption in my experiment.
then be distributed to other craftsmen, including armorers who made extensive use of leather products. I will not attempt to track the more specific exchanges of this trade network, which has been well documented by other scholars (Howard-Johnston 1998; Thomson 1981). It should be understood, however, that by the height of the medieval period, vegetable tanning had been sufficiently mastered to achieve a plentiful and high quality leather yield. This industry provided the raw material necessary to undertake and maintain studies in cuir bouilli, explored thoroughly during the 11th to 14th-centuries.

While craft treatises and illuminations supplement much of the evidence for medieval tanning operations, these practices also can be observed today in nice ethnographic hide processing. Even today, Nepal has a designated traditional leatherworking caste that maintains tanning operations analogous to those in the Middle Ages [Figure 2.10]. Morocco also has well documented traditional tanning methods that persist today (Higham 2006).

**A Brief Trajectory of Plate Armor Development**

The canonical late medieval and Renaissance suit of armor, composed of dozens of articulated metal plates that completely envelop the wearer, was likewise the product of thousands of years of experimentation. By the start of the 15th century, its iconic form had been achieved, drastically altering the battlefield tactics that followed (DeVries 2007). It is not my mission to catalogue the multiplicity of transformations that occurred en route to this final typology. However, a general
understanding of the trajectory of plate armor development from antiquity through the later Middle Ages end early Renaissance is necessary to appreciate the role *cuir bouilli* played in this maturation.

While the use of metal plate armor did not reach its apex of sophistication until the early years of the Renaissance, it is clear that plate armor had in fact existed for many years prior in Greek and Roman antiquity. Bronze breastplates and back plates were used by Greek hoplites (Sage 1996: 26). In Rome, the muscled cuirass or *lorica anatomic*, was anthropomorphically sculpted to resemble the torso [Figures 2.11 and 2.12]. These often elaborate armors were known to hold great prestige in ancient civilizations. In the early years of the first century AD however, there was a general trend toward mobility, and legionaries ditched their cuirasses and helmets in favor of long, rectangular shields. Following this brief dip in the ancient armor tradition, innovation provided new defensive implements that heeded the cry for mobility. Perhaps the most complex use of metal plate armor in antiquity was the Roman *lorcia segmentata*, which achieved widespread popularity among the

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19. Perhaps one of the most informative sources of Greek armoring is the *Iliad*, which provides four scenes of armor adornment. As evidence from this literary source, greaves seem to also have been used during this time to cover this shin (Sage 1996: 7).

20. Previous investigation into the status associated with ancient breastplates has been undertaken by (Richardson 1996) which examines votive bronzes from southern Italy and Etruria. The particular ways armor, in particular the imperial cuirass, is depicted in Latin verse has been also studied (Charles 2004). During the 2nd and 3rd centuries AD, highly decorated parade armor seems to have developed as a status item (Bishop 2006: 139).

21. This practice was perhaps most common among legions which faced barbarians in England. Flavius Vegetius Renatus, a Roman military writer in the 5th-century AD, recounts how this remodeling was met with grave results. While it is sure that most Germanic warriors they faced were also dressed simply, Roman soldiers apparently suffered great casualties following the removal of these armor elements from standard costume (DeVries 1998: 55).
legionaries in the 1st and 2nd-century AD (Robinson 1975: 174). Utilizing a system of overlapping iron bands to encase the torso and shoulders, this variety of plate armor was remarkable for the balance of protection and maneuverability it achieved [Figure 2.13]. Bands of metal were secured to strips of leather on the interior side, which when disassembled folded into a compact bundle.\(^{22}\) In the 2nd and 3rd-centuries AD, additional typologies of armor, such as lorica squamata and lorica hamata were developed [Figure 2.14 and 2.15].\(^{23}\) With the decline of the Roman Empire, it seems that much of this innovative technology faded from use. Its absence set back the development of more sophisticated armors by nearly three quarters of a millennium, giving rise to alternate means of bodily protection.\(^{24}\)

From the early medieval period through the Norman Conquest, the most defining defensive garment was the chain-mail hauberk. While the Romans experimented with chain-mail to a lesser extent, its popularity expanded immensely during the early middle-ages (DeVries et al 2007: 38). While mail triumphed,

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\(^{22}\) Reconstruction of the Roman lorica segmentata has been the subject of experimental archaeology projects seeking to understand how exactly this armor was articulated, confirming this collapsable capability as a distinct advantage in portability. (Robinson 1975).

\(^{23}\) These types of armors are in fact the earliest western examples of chain-mail and scaled armor (Bishop 2006: 63). The inundation of these armoring styles during the later centuries of the empire made armor more widely available, to Romans and Germanic barbarians alike. Despite the general decline in armor use following the Rome’s withdrawal, enduring examples provided a limited model for armor use during the early Middle Ages (DeVries 2007: 38).

\(^{24}\) Though a multitude of bronze allow and iron armor examples have been recovered, confirming their use with archaeological evidence, it must also be considered that molded leather might have also been a popular medium for these same defensive garments. Roman vegetable tanning industries were well established, providing the most necessary material need. Alas, in the absence of artifacts to corroborate this claim, the use of hardened leather in antiquity cannot be known with certainty.
substantial plate armoring practices seem to have largely fallen out of use. By the time of the Norman invasions in the eleventh century, chain-mail appears to be a standard arming implement among Normans and English alike, though subtleties do exist between the two (DeVries et al. 2007: 126).

Chain mail provided excellent protection against edged weapons. Constructed from a weave of thousands of metal rings, it was not easily sliced though, and offered the wearer nearly full range of motion, deforming like a piece of cloth in response to movement [Figure 2.16]. Not without its weaknesses, however, the flexibility provided little protection from heavy, crushing blows (Pfaffenbichler 1992: 8). To better insulate against blunt trauma such as this, early medieval warriors adopted heavy padded jackets known as *aketons* or *gambesons*. Nevertheless, any gap between links was vulnerable to piercing, either by arrows or the point of a blade. What is clear, that armoring technology during this time was still recovering in sophistication and complexity following Rome’s previous achievements.

After the Norman conquests, armor development was spurred with its most substantial developments since the forgotten contributions of Rome. In the 11th to 14th centuries, the indispensability plate armor was being realized yet again. The

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25 Cuirasses and helmets whether of iron or potentially leather appear to have only been very limited in availability, perhaps only to nobles. Shoulder clasps from the Sutton Hoo burial might confirm the use of a breastplate by this chieftain, corroborating the trend. While mail was certainly more common, Norse invaders are just as often described as fighting without any armor at all, which was very likely the case (DeVries 1998: 57; Bruce-Mitford 1978).

26 The two terms seem to be used interchangeably. While there are no surviving garments of this type, they were quilted with animal hair used for padding. Over the centuries, these coats grew longer to cover the thighs and arm. They would have been worn as a base layer of protection, underneath the mail hauberk (DeVries, 2007: 128; Blair 1958: 33).
devastating effectiveness of the English longbow and the crossbow signaled the need for more developed defenses (Van Creveld 1989: 20; DeVries 2007: 172; Nicolle 1988: 377, 470). Additionally, the Crusades stimulated exchange with Eastern and Byzantine cultures where scaled and hooped varieties of armor remained defensive hallmarks. Furnished with new cultural models, improving metallurgical technology, and defensive necessity, medieval armorers began experimenting with the possibilities of metal plate armor most extensively after 1250AD (Blair 1958: 39).

It was during this period, before the full realization of metal plate suits of armor in the late 14th and early 15th-century, that cuir bouilli is suspected to have been of greatest use. While iron would eventually prove to be the most effective platform for plate armor, many alternate materials are thought to have been experimented with. Hardened leather cuir bouilli is among the most hypothesized materials, though bone and horn are also likely candidates. John Waterer (1981) was one of the first scholars to recognize this possibility and laid the groundwork for further studies of cuir bouilli. He identifies the moldable quality of this material, well suited to producing anthropomorphic, fitted, pieces of semi-rigid leather. During the later 12th-century through the 14th-century, many images of what may be cuir bouilli armor can be identified. Yet our understanding of the material is impaired by the lack of surviving

27 Indeed the crossbow was seen as such a brutally effective weapon that attempts were made to ban its use against fellow Christians (Nicolle 2007: 73).

28 Arms and armor historian David Nicolle has done extensive research into the specific avenues of exposure scaled and splinted armor might have been appropriated by Western medieval cultures. This involved extensive exposure to the Eastern jashawn armor varieties, which affixed plates or scales to mail garments. While iron was definitely used for individual scales, hardened leather varieties might also have been used. Nicolle’s exploration of this possibility represents a highly focused study of leather in the canon of crusading era armor (Nicolle 2002: 181).
artifacts able to confirm this usage. As compared to the heavy iron armor to follow, *cuir bouilli* might have offered a lightweight and cost effective solution to the battlefield rigors of the day.

Despite the potential armor benefits offered by *cuir bouilli*, by the end of the fourteenth century, it seems to have been eclipsed by full metal plate suits of armor. These reached an apogee in 16th-century ‘Maximilian’ styles of Germany and Italy, noted for their elaborate gilding, engraving, and general craft mastery (DeVries et al. 2007: 178). Nevertheless, the proliferation of firearms forever changed armor concerns. While armorers undoubtedly strove to produce plates capable of resisting smoothbore ballistics, and succeeded in rare cases, the endeavor was ultimately futile (Hall 1997: 147). As gunpowder technology continued to be developed, it became all too apparent that the scales had tipped to offensive favor. By the end of the 17th-century, plate armor had been all but abandoned.

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28 Armorers seeking to provide protection against firearms responded by increasing the thickness of their armor. This *armor of proof* became so heavy and cumbersome that it could not be effectively worn into battle. Starting during the mid sixteenth century, most armor producing centers experienced drastically reduced outputs, though one prominent armorer is known to have stayed in business until nearly 1700 (Pfaffenbichler 1992: p.12).
Chapter 2 Figures:

**Figure 2.1:** Prehistoric hafting methods, using strips of hide to lash lithic blades to antler, bone, or wooden handles (Rots 2005: 62).

**Figure 2.2:** Prehistoric scrapers whose wear patterns indicate previous hafting and hide processing use (Rots 2005: 65).
Figure 2.3: Upper Paleolithic depictions of prehistoric peoples wearing what appear to be hide garments, likely produced using simple, untanned preservation techniques (Thomson 2006: 67).

Figure 2.4: A mural from the tomb of Baqt, Beni Hasan (Middle Kingdom 2000B.C.) which depicts warriors equipped with quivers and shields made from simple hide. In this instance, the hair has not been removed (Waterer 1981: 6).
Figure 2.5: Leather scraps from Roman London which bear inscriptions, perhaps signifying individual tanners or used to differentiate hides (Rhodes 1987: 178).

Figure 2.6: A medieval tanning operation, with facilities built around waterways (Thomson 2006: Manufacture of Leather 69).
Figure 2.7: A tanner from Germany removing hair from hides using a specialized knife. This image appears in a 15th-century German craft guide entitled Das Hausbuch der Mendelschen Zwölfbrüderstiftung zu Nürnberg (Munich) (Thomson 1998: 4).

Figure 2.8: Medieval tanners layering hides in tanning pits where they would remain for months or years depending upon the particular hide and intended usage (Thomson 2006: Manufacture of Leather 70).
Figure 2.9: A currier using another specialized blade to trim the tanned leather down to a final, uniform thickness (Thomson 2006: Manufacture of Leather 71).

Figure 2.10: Nepali tanners using simple methods believed to be analogous to medieval hide production. This particular operation uses earthen pits (Higham 2006: 83).
Figure 2.11 (left): Bronze loric a anatomic or muscled cuirass from the 5\textsuperscript{th} to 3\textsuperscript{rd} - century B.C. (Robinson 1975: 147).

Figure 2.12 (right): Statue of Augustus wearing a highly decorated muscled cuirass (Robinson 1975: 150).

Figure 2.13: Reconstructed Roman lorc ia segmentata armor (Robinson 1975: 175).
Figure 2.14: Roman *lorcia squamata*, made from many concave bronze plates threaded together, similar to eastern *lamellar* armor (Robinson 1975: 153).

Figure 2.15: Roman *lorcia hamata*, earliest western model of linked chain-mail armor (Robinson 1975: 172).
Figure 2.16: Chain-mail hauberk typical of the middle ages. This specimen is currently on display at the *Tower of London Armories Collection*. Combined with a padded gambeson coat, this reflects the armor most commonly worn by infantry soldiers until the 12th or 13th century when plate armor (including *cuir bouilli*) was experimented with. (DeVries 1998: 69).
Chapter 3: The *Cuir Bouilli* Quandary - Origins, Past Explorations, and Continuing Uncertainty

The true nature of *cuir bouilli* has long eluded historians, archaeologists, and craftsmen alike. Its limited surviving examples, paired with scant textual documentation and uncertain process of manufacture have left a gap in the current awareness of medieval leather working technology. While some attempts have been made by earlier scholars to understand this material, a satisfactory definition and comprehension of its properties has yet to be achieved. As such, the term has been loosely applied to all surviving forms of hardened leather, often times lacking a technological or historical basis for this categorization. It cannot be known with certainty how medieval *cuir bouilli* was crafted. However, by carefully considering existing specimens, artistic images, past explorations, certain traits may be inferred. These inferences can be used to produce modern analogs, which when tested reveal the functional capabilities of each. In my own investigation, I seek to examine the most compelling theories of this material, craft samples according to each, and objectively measuring their physical properties as related to plate armor -- one of its most commonly theorized uses. While past investigations may have produced authentic *cuir bouilli*, no attempts have been made to quantify the effectiveness of this material as a form of plate armor. I therefore seek to measure the performance of competing theories and potential methods of manufacture through armor specific tests. The outcome of these trials will be essential to establishing the most viable theories, verified by their functional performance. This, I believe, will enhance our understanding of *cuir bouilli’s* historic use and how it continues to exist today.
The Etymology of Cuir Bouilli

In order to best understand *cuir bouilli*, attention must be turned to the literal interpretation of the term. Translated from Norman French, *cuir bouilli* can best be understood to mean *boiled leather* or *boiled skin*. It seems to have first been recorded by Jean Froissart in his famous work *Chronicles*, which records the reign of Edward III and the Hundred Years War. In this context, Froissart alludes to small rowboats crafted from *cuir bouilli*, capable of carrying three men.\(^1\)\(^\text{30}\) Froissart’s use of the expression occurs late in the 14th century. Soon after, the term was appropriated or otherwise circulated by the famed English writer Chaucer, found in a single line of the *Canterbury Tales*. It can be found in *The Tale of Sir Topas*, a poem which records Sir Topas preparing for battle and explicitly mentions that “His jambeux were of quyrboilly” (Linn 1936: 301). Despite the variation in spelling, *cuir bouilli* appears to have traversed the English Channel from its Norman origins. *Jambeux* is understood here as a piece of armor which covers the leg from the knee down. To be of most effective use, this armor must be shaped or molded to fit the body, a characteristic *cuir bouilli* has frequently been understood to possess. This literary reference makes a preliminary case for the use of leather *cuir bouilli* as defensive armor.

Variations of the phrase make a handful of appearances throughout the 14th to 16th-century in England, with spellings ranging from *quyrbole* to *coerbuille*. It seems, however, that the term largely fell out of use after the 16\(^{\text{th}}\)-century. Following its 1513 occurrence in Gavin Douglas’ translation of Virgil’s *Aeneid*, there are no known

\(^{30}\) While this is in fact the first known written use of the phrase, John Waterer proposes that Froissart may be confused and is using the term incorrectly. Rather, Froissart may be referring to a Welsh *coracle* style boat, which is constructed from bulls hide, either raw or tanned, lashed to a wicker structural frame (Waterer 1981: 119). The hide used for these boats was not a hardened *cuir bouilli* variant.
recordings of the phrase until the late 19th century ("Cuir-bouilli" n. OED Online). Resurfacings in an 1880 catalogue of minor arts, cuir bouilli is understood as a molded and oftentimes decorated leather craft. While the designs cuir bouilli might be impressed with are explored, the precise methods of the manufacturing it are not identified. Already, the term has become generalized. During the roughly three hundred years where it disappears from the literary record, cuir bouilli comes to mean simply hardened leather. This separation of the term from its etymological origins obscures any technical implications the phrase might bear. These two terms were used almost interchangeably during the first half of the 20th-century, promoting the confusion we are faced with today.

The matter of cuir bouilli as armor is substantiated by the multitude of other defensive equipment that bears the same etymological root, cuir. Protective garments such as the cuirie and of course cuirass share the same Latin origin pertaining to animal hide or skin. These articles are called as such even when constructed wholly of plate metal (Nicole 1988: 595). It seems that these examples might be matured versions of defensive garments that were originally made from leather, hardened or not.

Taken literally, cuir bouilli might divulge a technical detail of its manufacture. While it has been readily assumed this necessitates boiling in water. It might also be considered that the French word for wax, cire, is only a slight misspelling away.

31 This source upholds that boiling leather in water is the accepted method for crafting cuir bouilli. However, it does not make any further suggestions of time, variations temperature, nor the possibility of baking or waxing as potentially viable means of hardening leather (Leland1880). Furthermore, the tooling techniques that this author associates with cuir bouilli could not be achieved with leather hardened in this proposed manner. It seem that the two major typologies of cuir bouilli, explicated subsequently in this chapter, are being conflated.
Many models support the use of beeswax treatments for hardening leather (explored later in this chapter). Such treatments, seeking to saturate the fiber network with wax, are distinct from those that employ shrinkage effects to induce hardening. Thus, the expression *cire bouilli*, might be understood as basins of melted wax used to achieve this effect. Over the course of centuries following this technology’s use and decline, it seems possible that the two methods have become conflated.

It was not until relatively modern times, pioneered by scholars such as John Coles (1962) and John Waterer (1981), that *cuir bouilli* became the focus of serious academic interest. The viability of all techniques is of continued dispute by those seeking to understand the material. These methods are the distinct area of focus in my own explorations as I seek to clarify potential *cuir bouilli* production methods and validate their effective use.

**Surviving Cuir Bouilli Artifacts**

As with any archaeological investigation, the surviving artifacts are of paramount importance. Of extant articles made from *cuir bouilli*, two distinct, yet affiliated typologies are most common. One type refers to the many black jacks, bombards, and leather tankards native to England. The other refers to waxed powder flasks, produced especially in Italy.

The majority of *cuir bouilli* blackjacks and tankards were produced in England from the 14\(^{th}\) through 19\(^{th}\)-century and are collected by institutions such as
the Museum of Leathercraft.\textsuperscript{32} These vessels are characterized by their bulbous middle portion and tapered lip. They may be equipped with a handle, or in some cases a rim for pouring [Figure 3.1]. They are rustic, durable drinking vessels, built with purpose and without pretension. The longevity of leather bottles use in England is opportune. As many sources recognize, the black jacks featured here have been in production for over 500 years if not longer.\textsuperscript{33} It is through sheer volume and persistence that these are the most extensively recognized and extant examples of \textit{cuir bouilli}.

Bottles are molded using a leather working technique known today as \textit{blocking}. This is achieved by soaking the leather in cold water, letting it fully saturate. Once wet, the leather is highly plastic, able to be bent, stretched, and modeled to nearly any desired shape. Cut patterns of leather can be wet molded over a wooden form, then stitched tight, creating a back seam on the vessel and handle, if desired (Waterer 1981: 68). Alternatively, the pattern could be stitched together, and then packed tight with sand to define the shape. This would have been especially useful in vessels with narrow mouths that would interfere with removing the mold (Davies 2006: 96).

\textsuperscript{32} This Museum of Leathercraft in Northampton houses one of the world’s largest collection of such bottles and other \textit{cuir bouilli} objects. Their online gallery provides the highest quality images I have access to for analysis of these objects, some of which I reproduce here (“Black Jacks” \textit{Museum of Leathercraft}).

\textsuperscript{33} The most extensive study of leather drinking vessels and containers has been published by Oliver Baker (1921). His account catalogs the subtle differences between vessels, general production trends, and the potentially ancient use of leather vessels as prototypical forms. Generally, smaller vessels might be called blackjacks while larger (1+ gallon) would be called bombards. The name black jack is actually derived from the silhouette of padded arming jack coats (like a gambeson), with which they share a silhouette.
To harden the leather into a rigid form, shrinkage treatments via controlled application of heat could be employed. This might have been undertaken in two distinct ways and is the subject of considerable dissent among scholars of *cuir bouilli*. One theory supports baking leather vessels in an oven, allowing ambient temperatures to induce shrinkage effects. Another promotes immersion in hot or boiling water as the most likely shrinkage operation. Moreover, the temperatures used in either process are disputed. The specific positions held by previous scholars will be explored later in this chapter. These recipes they champion are most informative to my own preparation procedures.

Once hardened, vessels were finished with a coating of pitch, resin, or wax on both interior and exterior surfaces [Figure 3.2]. This surface treatment serves primarily to waterproof the leather, though it might also have had a hardening effect (Waterer 1981: 69). In the cases where pitch was used, bottles have a distinctly black surface color, inspiring their name.

An overall decline in the production of leather drinking vessels occurred over the course of the 17th-century; through they continued to be made in substantial quantities in Winchester and Greenwich (Baker 1921). Curiously, Greenwich was also known to be a historic center of armor production in England (Cameron 2000: 27). The intersection of these two production centers is intriguing. *Cuir bouilli* techniques might have been used for both armor and drinking vessels here. When leather armor ceased to be of battlefield use in the 15th century, *cuir bouilli* methods might have been maintained for the production of leather bombards. These leather

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34 The chemical processes that dictate shrinkage properties in leather are discussed at length in Chapter 4.
vessels might preserve the methods of the *cuir bouilli* armor industry and offer cues to the plate armor itself.

The second major typology of *cuir bouilli* vessels refers to ornate powder flasks used by early riflemen [Figure 3.3]. These flasks were produced especially in Italy during the 16th-century (Waterer 1981: 92). They bear remarkable surface decoration, with carefully sculpted ridges and foliage motifs. These designs could have been achieved using repoussé techniques, where the leather was pressed and hammered into a carved mold, or intaglio techniques where the design was incised into the surface. However, the same *cuir bouilli* hardening processes used for English black jacks could not be used on these highly decorated flasks. The shrinking associated with hardening using hot water or ambient heat would have distorted the design (Lingwood 2013: 12). Instead, these flasks appear to be hardened using a medium of wax or pitch. Once a form was defined using blocking techniques, hot melted wax or pitch could be applied, absorbing into the leather’s fiber network in a process called *pitching* (Davies 2006: 96). After cooling and drying, the leather hardened substantially.

By saturating the leather with a stuffing agent, it is hardened without pronounced shrinkage effects. Moreover, a higher degree of decorative detail can be achieved in the absence of shrinkage effects [Figure 3.4]. Like their English counterparts, it has been suggested that the techniques to produce these flasks are remnants of those used to produce leather plate armor. However, these specific methods used here are likewise contested, as I will explore later.
While the molded vessels from England and Italy survive in greatest number and define the two basic typologies of *cuir bouilli*, there are a limited number of additional artifacts of use to this problem. Of particular interest is a Bronze Age leather shield recovered from an Irish bog in Clonbrin [Figure 3.5]. Its unique state of anaerobic preservation three meters below the level of the bog provides a rare glimpse into the prehistoric usage of molded, hardened leather. Measuring 50 cm in diameter and almost a 6 mm thick, the leather was most likely taken from a mature bull and appears to be vegetable tanned (Armstrong 1909: 259). The shield is molded with a central boss that protrudes from its surface. Three additional concentric rings surround it with raised studs in between. The shield shows no indication of having previously been attached to a backing of any sort, either wooden or metal (Armstrong 1909: 260). To be of any defensive use, the leather itself must have been hardened, a quality it retains even today. More auspicious still is the carved oak mold this shield was formed on [Figure 3.6]. After soaking in water, leather could have been pressed into these grooves to block out the shape. Once defined, hardening measures could have been applied to the provide rigidity necessary for defense. The particular hardening methods used on this prehistoric *cuir bouilli* shield was the study of an experimental archaeology by John Coles (1962). His experimental attempt informed my own project and will be discussed later in the chapter.

A molded leather cup might substantiate the prehistoric usage of *cuir bouilli* methods [Figure 3.7]. It too appears to be hardened using shrinkage techniques to achieve a rigid quality. As remnants of hair in the hide indicate, tanning methods were still been refined. Nevertheless, shrinkage mechanisms seem to have been
explored millennia ago. While *cuir bouilli* might not have achieved full sophistication until the Middle Ages, its basic qualities might have been employed anywhere vegetable tanned leathers were being developed.

Leather fire helmets used throughout the 17th and 18th-centuries might represent another remnant of *cuir bouilli* armor technology in a defense application. Constructed from four pieces of leather stitched together in quadrants, these helmets bear prominent ridges along the main axes [Figure 3.8]. Like other objects constructed from *cuir bouilli*, they were wet molded over a form. Hardening measures of either baking, boiling, or both might have been used to produce their rigid protective quality. Helmets such as these were used during the Great Fire of London in 1666, though it is unlikely that this date defines their introduction. Variations on this form continued to be used by miners in the early 19th century (Waterer 1981: 36). Bearing further resemblance to the blackjacks and bombards discussed earlier, these helmets often were pitched with wax or pine resin, waterproofing them and contributing to the overall hardness.

Though *cuir bouilli* helmets can be confirmed with surviving examples, other examples of *cuir bouilli* plate armor are nearly unknown in the archaeological record, with one further exception. Preserved at the Tower of London Armories, a single *cuir bouilli* crupper survives [Figure 3.9] (Waterer 1981: 74). Like previously explored examples, this crupper is carefully molded, utilizing the plastic properties of vegetable tanned leather. The crupper’s precise date of manufacture cannot be known, though it has been tentatively dated to the mid-16th-century (Waterer 1981: 73). It should be noted that this date follows the greater adoption of metal plate armor.

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35 A *crupper* is a piece of defensive armor used to protect the flank of a horse.
Nevertheless, *cuir bouilli* might have continued to be produced for less essential military personnel, such as horses exhibited here, or simply those who could not afford metal plate.

**Deciphering Visual Images of Cuir Bouilli**

While literary references and extant leather vessels would suggest that *cuir bouilli* was a common aspect of medieval material culture, few armor examples remain. In this absence, alternate means must be undertaken to understand its place and function in the wardrobe of a medieval warrior. David Nicolle, a historian of arms and armor, has made meticulous observations and considerations of the many typologies of armor that characterized Europe and the Near East during the Crusades. In a comprehensive two volume set entitled *Arms and Armor of the Crusading Era 1050-1350* (1988), Nicolle includes thousands of illustrations, capturing the nuances of regional armor styles at this time. This catalogue might be used to infer the role of *cuir bouilli* in the costume of a warrior from this period. While some illustrations are taken from surviving armor, the majority reproduce images of warriors from other visual arts such as sculpture, illuminations, or stained glass. Nicolle’s illustrations capture the subtle differences in materials that might be depicted in each case. His attention to visual detail is accompanied by close analysis of these marking systems as Nicolle makes attempts to decipher their often times ambiguous appearances. Nicolle identifies a number of examples that appear to represent *cuir bouilli* armor. The investigation that follows highlights some of these most persuasive instances, identified by Nicolle, which help to reconstruct the role of *cuir bouilli* armor.
Nicolle’s analysis supports two principle regions where *cuir bouilli* hardened leather may have been most prevalent during the 11\(^{\text{th}}\) to 14\(^{\text{th}}\)-centuries; England and the various Kingdoms of Italy. Furthermore, the style and application of hardened leather in each region has distinct trends. Two contrasting varieties of *cuir bouilli* armor might have been common during this time. As blackjacks and bombards from England compared with ornate powder flasks from Italy suggest, each armoring methods appears to have surviving objects which can corroborate this distinction. These contrasting methods produce materials with dramatically different physical properties. Each lends itself to certain applications more effectively than others. This might be reflected in these images.

While Nicolle has identified certain persuasive examples, it must be recognized that medieval art was not concerned with naturalism or depiction of the world as it appeared. It is highly stylized, adhering to established standards of representation. Moreover, it is limited in detail. As Waterer has pointed out, “it has been impossible to indicate by a plain stone surface the difference between polished metal plate, *cuir bouilli*, buff leather, and even a finely woven fabric... where no actual examples have been preserved, the truth is conjectural” (Waterer 1981: 70). Their ambiguity requires interpretation. As a result, none of the following examples can be taken as proof that *cuir bouilli* was part of the depicted costume. However, if these elements are understood as such, they might provide models that suggest the specific application of *cuir bouilli* in armor.

English *cuir bouilli* armor elements appear to be more plate oriented, utilizing flat, inflexible sections of leather to provide protection for the torso and limbs.
Nicolle draws particular attention to the way shoulders and surcoats interact in English depictions of warriors as evidence of underlying rigid armor, potentially made from *cuir bouilli*. In one such example taken from an English version of the *Chanson d’Aspremont* in 1250-75 [Figure 3.10], a group of armed cavalry is depicted wearing a fully armored costume. Full-length mail hauberks are worn by all figures and quilting around the knee of the middle knight might indicate the use of a padded *gambeson* as an intermediate armor layer. The detail of most interest though is the interaction of surcoats with the shoulders and torsos of these individuals. Especially prominent on the leftmost knight, his surcoat is suspended high on the shoulder and is unusually squared in form. Rather than draping over the body, following its natural contours like as a piece of fabric ordinarily would, the surcoat seems to be supported by an underlying structure which imposes this silhouette. Nicolle suspects that this signals a concealed cuirass of sorts (Nicolle 1988: 367). This image precedes the widespread adoption of metal plate as the preferred defensive equipment -- the individual does not appear to have any other armor that explicitly makes use of metal plate. Rather, the image seems to represent the development of plate armor where leather armor was experimented with as *cuir bouilli*. In the absence of other metal plate defenses, *cuir bouilli* is entertained as the material this cuirass is made from.

The English tendency for simply formed leather plates is apparent in an effigy of Sir Robert de Vere, found in Essex, dated to the second half of the 13th-century [Figure 3.11]. During this inventive period where armorers were experimenting with the possibilities of plate armor, *cuir bouilli* might make another appearance. This figure is equipped with plates covering his knees, fastened directly to the softer
padded *cuisses* (armor for the knee and thigh). Though iron is equally likely, Nicolle makes a case that *cuir bouilli* could just as easily be depicted here (Nicolle 1988: 357).

Nicolle substantiates the use of *cuir bouilli* hardened leather among English warriors during the numerous additional examples, most all of which rely upon interpretations parallel to those just discussed. The picture he develops is of rigid, unadorned leather, which only vaguely mimics the anatomical proportions. When the collection of surviving English bombards and other leather drinking vessels is considered, objects that are thought to preserve this armor technology, the necessity for such forms is reinforced. If these elements of leather armor were produced using techniques akin to the leather bottles, their hardening would have been produced by exposure to shrinkage temperatures, either by boiling or baking. Leather that has been hardened in such a way, however, is difficult to mold into precisely defined shapes. The contraction of its fibers distorts the shape. As others such as Lingwood have pointed out, the corresponding drinking vessels are very often characterized by imperfections and distortions as a result of this forming process (Lingwood 2013: 8). Molding leather to fit the body exactly, it seems, would have been a troublesome process with defects only becoming amplified in larger works. Thus, the projection of these potentially *cuir bouilli* cuirasses above the shoulder might be attributed to the difficulty of the medium itself. Rather than conforming to the body precisely, the shape is generalized. Using plates may have been a response to this realization. In smaller scale, the shape can be controlled more accurately, less affected by the contracting leather fibers.
Interpreting the armor images from Italy reveals a contrasting style of *cuir bouilli* defensive elements. Unlike their English counterparts, ornate decorative aspects and a closer fit form characterized Italian *cuir bouilli* armor. Their distinct appearance can be attributed to the beeswax “stuffing” process that was used to harden the leather. Nicolle uses effigies from burials in Campania, dated to the first half of the 14th-century to support the use of *cuir bouilli* armor elements [Figure 3.12]. These figures appear to wear highly decorated *rerebraces* that cover their upper arms. They bear obvious adornments of floral motifs and zoomorphic elements and appear to be fitted to the body. Moreover, there are certain elements that are readily identifiable as metal plate. The figure on the left wears splinted *vambraces* around his wrist and lower arm (Nicolle 1988: 573). Additionally, his greaves appear to be of metal plate with distinct rivets. The limited use of metal splints signals that earlier, less mature forms of metal plate armor still predominate. Thus, a fusion of armor materials might be present on this individual. Since the metal elements are easily recognizable, larger plate elements might be made of *cuir bouilli*. As Italian powder flasks indicate, waxed *cuir bouilli* is a more pliable material. It readily accepts forms and complex surface decoration where shrunken leather will not. These differences might be reflected costume of this effigy.

Another effigy Nicolle employs to demonstrate regional difference in *cuir bouilli* use is from the tomb of Filippo dei Desideri, carved in 1315 in Romagna [Figure 3.13]. Nicolle draws attention to this figure’s greaves, as evidence that a semi-rigid leather is being used. These greaves are fitted tight to be body, as might be expected from waxed *cuir bouilli*. Perhaps most telling, however, is the inclusion of
laces on the inner leg, a fastening system not usually seen on iron examples (Nicolle 1988: 489). Since this type of *cuir bouilli* retains a degree of elasticity and flexibility, the laces could be used to pull the molded form tighter around the leg, a feature which is not characteristic of iron plate. Moreover, the greave sits high on the leg, covering the entire front of the knee and perhaps the reverse as well. At this crucial joint, flexibility of the material would be necessary to preserve range of motion, an impossible effect if this section were constructed from iron.

The full extent of *cuir bouilli* armor use in an Italian setting might be revealed by an effigy of Lorenzo di Niccolo Acciaiuoli, carved in Tuscany in 1353AD [Figure 3.14]. This figure retains his chain-mail hauberk as a base layer of protection (perhaps with a gambeson beneath) but covers it almost entirely with armor that appears to be made from waxed *cuir bouilli*. Familiar elements such as tooled greaves are identifiable, boasting the artistic character only possible using these waxed production methods. Furthermore, the inclusion of splinted elements, as seen in the *vambraces* and *cuisses*, indicates that there is only selective use of iron in this warrior’s costume. The presence of readily identifiable metal splints, preceding the use of full blown metal plate, emphasizes the likelihood that other elements are constructed from *cuir bouilli*, especially those which are decorated. In this effigy, the transition from soft armors like unhardened leather or chain-mail to metal plate is apparent. A variety of armor materials seem to be present, especially regional variations of *cuir bouilli*.36

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36 As Nicolle also explains, Niccolo Acciaiuoli was a servant of the Angevin Kings of Namples who spent much of his career in Greece. Here, contact with the Balkan states and remnants of the Byzantine Empire might have inspired the use of hardened leather armor in southern Italy. Moreover, he proposes
Nicolle’s contributions attempt reconstruct the role of *cuir bouilli* in the costume of a medieval warrior. His close visual analysis, paired with a lifelong career studying arms and armor from this period gives him an unusually keen eye and authority to decipher the historical marking systems. Most crucially, Nicolle’s interpretations corroborate the visual aspects of regional *cuir bouilli* apparent from leather vessels. Thus, it seems clear that two distinct varieties of *cuir bouilli* armor were known. Nicolle does not concern himself with the specific procedural aspects of each. While the visual differences might be fully elucidated, the production processes and performance of either remains to be evaluated. If the strengths and weaknesses of shrunken (boiled or baked) compared to waxed *cuir bouilli* can be demonstrated, reasons for their abandonment can be better understood and the trajectory of plate armor development expanded upon.

**Previous Investigations of Cuir Bouilli**

Inspired by the *cuir bouilli* shield discovered at Clonbrin, Ireland, Coles (1962) released an account of his attempts to recreate this shield. Coles made four distinct attempts to harden the shield. Each recipe began by soaking leather in cold water, and then shaping it using a copy of the wooded mold recovered with the shield [Figure 3.15]. After drying at ambient room temperature, the four unique treatments were applied. Coles’ first hardening attempt was a wax immersion meant to stuff the fibers of the leather. The leather is recorded as becoming extremely hard, inflexible, and impervious to water. Coles’ second hardening treatment immersed the leather in a

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that this figure may be wearing a *coat-of-plates*, constructed from a laminated layers of iron plate and leather, perhaps *cuir bouilli*. (Nicolle 1988: 490; Nicolle 2002: 206).
water bath at 80ºC for 30 seconds. This sample was described as being ‘quite hard’ but flexible (Coles 1962: 178). In his third attempt, the leather was dried in an oven at 70º-80ºC for 2 minutes. This sample was said to have shrunk and curled somewhat, making it semi-rigid, but distorted. Coles’ final sample was achieved by scalding the surface of the leather with boiling water poured over it for two minutes. This sample was said to be harder than the others, but lacked resistance to water (Coles 1962: 179).

Though Coles produced four samples in this experiment, I understand his approach as three distinct methods of producing *cuir bouilli*: hardening with heated water, hardening with ambient temperatures, and hardening with wax additives. Samples 2 and 4 which make use of 80ºC and boiling water, respectively, are variations on the same technique; hardening leather with water which meets or exceeds the threshold of shrinkage temperature. This particular technique is the most literal interpretation of the phrase as *boiled leather*, and thus seems an approach that must be present in any experimental investigation of *cuir bouilli*. Coles’ attempt to harden the leather using wax is akin to the pitching treatments explored earlier. Coles eventually concludes that this was the most successful of his four samples (Coles 1962: 178). Coles also attempted to test their function. The leather shields were informally tested in sparring scenarios against a sheet bronze shield of the same dimensions [Figure 3.16]. As Coles points out, the bronze shield was immediately bent or cut by the sword strikes, but leather resisted the attacks well (Coles 1979: 180). However, his experiment has many uncontrolled variables and the performance cannot be quantified.
While I believe that Coles has accurately identified the three the most compelling basic recipes for manufacturing *cuir bouilli*, his experiment ultimately falls short due to the limited amount of samples produced. With only four samples to represent three distinct approaches to the medium, none of the variables can be explored thoroughly. Rather, seemingly arbitrary measures of time and temperature are chosen. This particular experiment could have been more enlightening if multiple attempts at each particular method were made, altering variables such as time and temperature slightly in each case to observe the scaled effect of each. Nevertheless, Coles takes an impressive first step into the experimental potential of *cuir bouilli*. While his measurements are qualitative, at best, his findings do suggest that these methods may be viable means of hardening leather, using only materials available in a medieval setting. There is still much left unanswered amongst his samples -- in particular, their performance relative to one another. While ‘quite hard’ and ‘tough’ are used to describe certain samples, empirical data is needed to describe these differences objectively.

John Waterer is widely recognized as one of the preeminent scholars of medieval leather and holds his own theories concerning *cuir bouilli* manufacture. Waterer is of the firm opinion that the literal interpretation of the phrase as *boiled leather* is erroneous, insisting that it destroys the quality of the leather (Waterer 1981: 64). While it is true that boiling would sufficiently induce shrinkage in the collagen fibers, Waterer believes that prolonged exposure to such temperatures would break down this essential network, weakening the leather and rendering it unusable for any purpose, be it armor or domestic. Rather, Waterer insists that the phrase more likely
originated from workshop jargon as *warm*, but not hot water, used to prepare leather for molding. Indeed, he believes that the distinguishing characteristic of *cuir bouilli* was its ability to be molded to a desired shape as a plastic medium, a property that can be elicited from exposure to warm water.

Molded forms, Waterer postulated, could be dried at warm to moderate heat to set the desired form permanently and produce a marginal degree of rigidity and toughness compared to untreated leathers. This, he believed, was achieved due to the evaporation of various lubricating agents in the hide when exposed to heat. (Waterer 1981: 66). Without the fats and oils that would normally lubricate the fiber network and provide suppleness, fibers would become compacted and fixed in place. However, Waterer is insistent that only moderate heat can be used, imploring that temperatures exceeding 50-55ºC would render the material useless (Waterer 1981: 68). At these higher temperatures, the leather is dried to such an extreme degree that it would become brittle and thus weaker, despite a superficially harder appearance.

Waterer’s contribution to the current understanding of *cuir bouilli* cannot be understated. His comprehensive research of leather goods and their relationship to warriors of the last three millennia has led him to ponder this question more anyone had previously. Yet despite his understanding of the historical context for *cuir bouilli*, Waterer’s theories remain just that -- theories. He certainly held strong opinions regarding methods of *cuir bouilli* production and seems to have experimented with them to some degree. Using scraps from leather suitcases, Waterer produced small-scale samples of boiled and baked leather *cuir bouilli*. In another experiment Waterer boiled a piece of leather for over 30 minutes until it turned into a gelatinous mess. As
Lingwood (2013) has pointed out though, Waterer explored only a small range of the potential hardening properties. Moreover, Waterer never published an account of these experiments that could adequately differentiate these methods from one another. Without a comparison of the proposed procedures, it is impossible to understand the resulting effects each might have, and even more difficult to speculate on their viability as leather plate armor.

Rex Lingwood, a Canadian artist and designer, has undertaken the most thorough experimentation with *cuir bouilli*. On his website, Lingwood explains that his initial attraction to the medium some 30 years ago was due to the “discrepancy between the literal meaning of the term *cuir bouilli* and the process Waterer believed it described” (Lingwood 2013).37 Every since, Lingwood has been exploring the plastic medium of molded leather, making great achievements both technically and artistically. Lingwood has developed his own methods for crafting *cuir bouilli* that confront those proposed by scholars such as Waterer. He supports that boiling leather, exposing it to temperatures that greatly exceed the shrinkage threshold, is in fact a viable means of crafting *cuir bouilli*. Lingwood warns that his methods are not necessarily meant to be historical reconstructions. Nevertheless, his mastery of the medium and documentation of methods has much to offer.

Lingwood has worked as an artisan, experimenting with the effects of different heat treatments on leather and how they can be used to induce hardening and structural rigidity. His portfolio of work consists mostly of bowls, tables, and chairs

37 Rex Lingwood’s personal website and gallery may be found at [http://www.makersgallery.com/rexlingwood/cuirbouilli-bkgd.html](http://www.makersgallery.com/rexlingwood/cuirbouilli-bkgd.html). It does not seem to be updated regularly (last update in September of 2013), but hosts Lingwood’s most thorough writings on the subject of *Cuir Bouilli* as well as a portfolio of work.
made wholly or in part from molded, hardened leather [Figures 3.17 and 3.18]. Though Lingwood is not an academic in the tradition sense, like Waterer, he is as well if not, better informed to tackle the *cuir bouilli* quandary. For Lingwood, the practical application of *cuir bouilli* methods is his main focus. His prolonged experience working with molded, hardened leather over the last three decades offers him developed intuition with the medium [Figure 3.19].

Like any art form, there is a steep learning curve. Given a material as nuanced as leather, fraught with subtle inconsistencies, a certain amount of time is needed to achieve mastery with it. With familiarity, a more discerning eye might be developed, offering cues that inform methods. As experience develops over time, methods can be tailored to each piece of leather and project. Adjusting times, temperatures, and other procedural aspects to best suit each project allow Lingwood to attain a superior product. This is how Lingwood is able to make the claim that *boiling* leather is indeed a viable process for crafting *cuir bouilli*. He modifies the definition of boiling as “a quite viable process for hardening leather if it is taken to mean the leather has in whole or in part been raised to shrinkage temperature” (Lingwood 2013: 10). By this definition, leather that has been immersed in 85-90ºC water for only 30 seconds constitutes being boiled. Lingwood’s experience allows him to recognize these ideal time and temperature zones where a balance is struck between material and method.

Though Lingwood does not concern himself fundamentally with leather armor, he does acknowledge its likely existence and shared origins with the drinking vessels that succeed it (Lingwood 2013: 15). He recognizes the distinction between the two typologies of *cuir bouilli* explored previously. One type is composed of
objects that have been shrunken and molded through exposure to greater than shrinkage temperature conditions, either in water or a warm ambient environment. Lingwood confirms that most, if not all of the bottles, bombards, and blackjacks produced in England from roughly the 12th through 19th-century belong to this type (Lingwood 2013: 2). These vessels exhibit obvious surface hardening, evident in the contracted leather fibers. As the leather dries and the form sets, subtle warping occurs as these contractions impose a shape that deviates from the mold. Lingwood sites cracking around the rims of bottles as evidence that the form has been re-corrected while the object dries (Lingwood 2013: 10). These distinct markings, he believes, are analogous to his own experience working with boiled leather as a medium for his artistic endeavors and confirm the use of this technique in historic leather works.

Lingwood also explores the possibility that these vessels were baked instead of or in addition to boiling. In one particular instance, he notes the presence of deep wrinkles around the rim of a blackjack as evidence that these vessels were prepared using temperatures that greatly exceed the shrinkage threshold [Figure 3.20]. Their prominence on the surface of this blackjack suggests to him that they were baked at a much higher temperature than Waterer’s maximum ~50°C. If low, gradual heat were applied, as Waterer has postulated, such outward evidence of shrinkage could never occur. Rather, Lingwood’s own leather working experience indicates that these effects could only be reproduced using dramatically higher temperatures, as high as 150°C (Lingwood 2013: 11).

Lingwood also considers the second type of cuir bouilli objects, ornate powder flasks and decorative boxes, primarily of Italian origin. He supports that these
objects were produced using distinct methods, necessary to retain the elaborate surface ornamentation while offering functional rigidity. As the blackjacks discussed above demonstrate, contraction of the leather will leave deformations at the surface. If the decorative tooling were impressed before any hardening measures were taken, the design would surely be distorted. Given the level of precision and definition which characterizes these flasks, their surface embellishment must have either been added after any exposure to shrinkage temperature -- or that they were not shrunken at all. Adding surface decoration after hardening is impossible with shrunken examples. Their hardness is attributed to a permanent restructuring of the fiber network that cannot be reversed. Thus, the leather cannot be sufficiently re-softened to allow a design to be impressed after initial molding. Instead, they were stuffed with a medium of beeswax or another agent like pine pitch to harden the leather while averting shrinkage effects.

Impressing such intricate designs in leather requires careful application of heat and moisture, necessary to soften the leather and provide a pliable working surface. Previous understanding of the technique has endorsed a process where the leather is tooled using traditional wetting and stamping processes, and then hardened after the fact using a stuffing medium. As Lingwood points out however, this would invite excess wax or pitch to accumulate in the carved or recessed areas (Lingwood 2013: 6). Achieving an even surface coating, as the many fine Italian samples boast, would be of exceptional difficulty, requiring the wax to be carefully scraped out of each cavity. Lingwood has been led to believe that these decorative aspects may have been added after any stuffing processes. If the leather were waxed prior to decoration, it
could be reheated, softening the wax and restoring its pliability momentarily. Heat could be applied to focused areas, allowing the artisan to selectively work on different aspects of the design. Once impressed, the relatively rapid cooling of the wax sets the design permanently, or until further reheating and reworking.

The most extensive scientific study of the basic material properties of *cuir bouilli* was conducted by Esther Cameron (2000). In the absence of data collected by Waterer, she has investigated one of his fundamental theories; that leather can be hardened by the controlled application of gentle, dry heat. Her experiment exposed identical strips of leather to temperatures ranging from 45ºC to 120ºC for times ranging from only minutes to a full 32 hours. Once prepared, a specialized device was used to measure the elasticity of each sample as an indication of hardness. Cameron found that Waterer’s proposed method of hardening the leather using moderate heat (no greater than 50-55ºC) was unsuccessful (Cameron 2000: 31). Using a microscope to further examine the fiber structure of heated and unheated leathers revealed only minimal changes at this temperature. Though she refutes Waterer’s theory, Cameron also identifies a temperature range for baking which did seem to produce appreciable hardening effects. Her experiment attests that baking leather at ~95ºC is far more effective at hardening the fiber network (Cameron 2000: 230). Thus, Cameron corroborates Lingwood’s claim that baking at greater than shrinkage threshold temperatures is a viable means of hardening leather.

Lingwood makes a case that “[Waterer] is simply mistaken that leather taken to shrinkage temperature cannot be formed” (Lingwood 2013: 9). Indeed the two disagree over the functional effect of shrinkage temperatures on leather. The fact
remains that Waterer condemns the use of hot boiling water while Lingwood embraces it. These dissonant theories also apply to baking procedures. While each claims success with one particular method, the two require further scientific study of their effects, especially as they affect use as plate armor. Using these previous investigations as a foundation, I intend to isolate the key variables for each treatment, verifying their essential physical effects. In my own experiment, time, temperature, and application of stuffing treatments will be scaled to create contrast within the sample group. The simple, but definite difference in variables will draw more distinct trends in the ultimate testing performance. While the ideal technical methods for producing cuir bouilli might not be realized within my sample group, they should offer directionality to this ideal. Moreover, it still seems necessary to demonstrate the effect boiling water will have on leather, especially how it affects use as plate armor. This might confirming Waterer’s dismissal of the technique, or support Lingwood’s reinterpretation of the phrase.
Chapter 3 Figures:

Figure 3.1: *Cuir bouilli* black jacks and bombards in the collection at the *Museum of Leathercraft*. Leather vessels like these were common from the late Middle Ages through the 18th century in England (“Black Jacks” *Museum of Leathercraft*). Moreover, they establish the first type of two main *cuir bouilli* varieties. These vessels have been hardened using shrinkage effects.
Figure 3.2: Another medieval black jack from the *Museum of Leathercraft* collection (Waterer 1981: 75). The waxed surface sheen and rough dimensions are apparent in this example.

Figure 3.3: A 16th-century Italian powder flask from the *Museum of Leathercraft* (Waterer 1981: 93).
Figure 3.4: Another Italian powder flask. The surface in the previous two figures is significantly more exacting than the first. This ornamentation could not have been achieved with shrunken leather *cuir bouilli*. Rather, waxed stuffing processes appear to have been used (Lingwood 2011: 5).
Figure 3.5: Front and back faces of the Bronze Age leather shield from Clonbrin, Ireland (Armstrong 1909: plate XIII). It retains its rigid quality even today and was perhaps hardened using methods akin to cuir bouilli, albeit many centuries preceding the medieval period most in question.

Figure 3.6: The oak mold recovered with the above shield, used to define shape using blocking techniques, after which hardening treatments could be enacted (Waterer 1981: 27). This artifact is in the collection of the National Museum of Ireland, Dublin.
Figure 3.7: A prehistoric leather cup that appears to have been hardened using prototypical cuir bouilli methods. Part of the collection at the Cuming Museum, Southwark (Waterer 1981: 65).

Figure 3.8: 18th century fire helmet made from cuir bouilli (Davies 2006: 100). It bears distinct resemblance to the black jacks discussed earlier.
Figure 3.9: This horse crupper from the Tower of London Armories is one of the only surviving examples of *cuir bouilli* armor known (Waterer 1981: 73).

Figure 3.10: These figures clearly wear mail hauberks with padded gambesons beneath, as was typical of the Middle Ages. However, their squared shoulders suggest a rigid cuirass in addition, perhaps made of *cuir bouilli* during the centuries preceding the widespread adoption of metal plate (Nicolle 1988: 832). *Chanson d’Aspremont, England, c.1250-75 AD, (British Library, Ms. Lansdowne 782 f.12v, London, England).*
Figure 3.11: This figure wears knee plates over what appears to be a padded jack. Early models of plate armor are apparent here – these plates might have been made from *cuir bouilli* during this maturation metal plate (Nicolle 1988: 824). *Effigy of Sir Robert de Vere, Essex, c.1250-1300 AD (in situ Church of St. Mary, Hatfield Broad Oak, England).*

Figure 3.12: Italian effigies with what appear to be *cuir bouilli* armor elements. The decorated rerebraces are believed to be of wax stuffed *cuir bouilli*, a type distinct from shrunken leather (Nicolle 1988: 960). *Effigies of members of the Barrile Family, Campania, c.1300-50 AD (in situ Church of San Lorenzo Maggiore, Naples, Italy).*
Figure 3.13 (left): In this image, *cuir bouilli* greaves might be depicted. Laces on the inner leg are not typically seen on metal examples. This could indicate a semi-rigid form of hardened leather (Nicolle 1988: 900). *Tomb slab of Filippo dei Desideri, Romagna, c.1315 AD. (Museo Civico, Bologna, Italy).*

Figure 3.14 (right): This image might represent the peak usage of *cuir bouilli* armor. Metal splint vambraces and cuisses are present, suggesting that the more ornamental elements are made of waxed *cuir bouilli*. A coat of plates might also be depicted here (Nicolle 1988: 901). This costume exemplifies the transition from chain-mail to metal plate. *Effigy of Lorenzo di Niccolo Acciaiuoli, Tuscany, c.1353 AD (in situ Certosa di Valdema, Florence, Italy).*
Figure 3.15: Coles blocking out the shape of his replica Bronze Age shield (Coles 1979: 199).

Figure 3.16: Coles informally testing his leather shields against bronze duplicates (Coles 1979: 180).
Figure 3.17 (left): 840.2.99, a *cuir bouilli* bowl molded using shrinkage effects (Lingwood 2013, *Makers Gallery*).

Figure 3.18 (right): 944.5.08 Chair #8 (Lingwood 2013, *Makers Gallery*)

Figure 3.19: 863.1.00, one of Lingwood’s more intricately sculpted pieces, demonstrating his skill with the medium. Precise control of hardening effects is necessary to achieve such detail (Lingwood 2013, *Makers Gallery*).
Figure 3.20: Deep wrinkles around the rim of a medieval black jack. In Lingwood’s experience, these contraction patterns are only formed using temperatures that greatly exceed the shrinkage threshold (Lingwood 2013: 11).
Chapter 4: The Science of Leather

Leather has always been recognized as a unique and highly functional material, well suited for countless high stress applications. Its strength and long wearing properties are hardly surpassed even today, despite the advent of modern textiles. In demanding physical environments that call for a combination of features such as abrasion resistance, high tensile strength, and protection from cold, wind, and water alike leather has no substitute. A properly prepared and cared for leather garment will readily accept the abuse from even the most demanding of environments and activities. Scratches might dig into the outer grain, yet this superficial surface damage rarely defeats the material as a whole. If uncompromising durability of leather is its most desirable trait, it might be well suited for use as plate armor. However, the features full-grain leather offers are not present in the animal hide from which leather is processed. Rather, tanning processes and preserving salves permanently affect the chemical makeup of the hide, drawing forth these valued qualities. Without these dramatic transformative processes, raw hide is highly volatile and prone to decay. Thus, the scientific principles that determine the particular material quality of leather must be explicated. In doing so, the scientific basis for cuir bouilli as an outstanding example of modified and optimized protective leather will be explored.

38 Textiles like Cordura, Kevlar, and other synthetic weaves have grown in popularity during in recent years. Kevlar’s fame can be mostly attributed to its application in bullet-proof vests. They are frequently used in high wearing outdoor or work clothing -- wherever strength and durability is paramount. Previously, leather occupied this role among fabrics, but due to rising costs is seen less frequently, or on premium items.
**Hide and Leather**

In order to understand the strength and stability leather exhibits, it is first necessary to make a distinction between *leather* and *hide or skin*. While leather is exceptionally durable, hides and skins are unstable and subject to rapid deterioration. In order to be considered leather, a skin must be processed and subjected to tanning treatments that preserve the fibrous network against natural decay. Indeed, this has been recognized as the fundamental difference between leather and hide. While leather is resistant to microbiological attacks, raw skins are susceptible to rapid bacterial degradation (Thomson 2006: *Nature and Properties 1*). Thus, it should be noted that the hide products used by early man, prior to the refinement of tanning processes, would not have been classified as true leather by today’s standards (Waterer 1986: 7). While preservation techniques such as salting and slow drying in the sun can control the dehydration of a hide, temporarily stabilizing the fiber networks, exposure to water reverses these attempts almost immediately and the skin is again in danger of bacterial decay. In contrast, tanned leather is capable of being saturated with water and dried repeatedly without adverse affects. This reveals another crucial characteristic of leather, its suppleness and opaque appearance. Raw skins, even those dried in a well-controlled environment, are generally hard and brittle. In contrast, leather will remain flexible like living skin, far more durable than raw hides, which are easily cracked or broken when dried (Thomson 2006: *Nature and Properties 2*).

There is also a liminal category between hides and leather called *pseudo leather*. Pseudo leathers refer to raw hides that have been coated and impregnated
with stable fatty materials. Fats coat the individual fibers of the hide, preventing the network from drying out completely and allowing for some pliability. This has the advantage of protecting the fibers from rehydration in water that would invite decay, but the hide is not chemically altered (Thomson 2006: *Nature and Properties* 1). Pseudo leathers appear to satisfy the requirement of resistance to bacterial degradation, but only so long as they remain sufficiently coated in fatty insulators. This material dries out naturally and must be replenished periodically to retain these properties. If the fiber network dries out from neglect or overuse, the skin can be saturated by water and rot when not taken care of properly. Historically, many different types of pseudo leathers were in use, though they are seldom seen today. Early precursors to modern tanning methods such as tawing and pickling might be considered pseudo leathers and are still used in niche hide processing. Even still, they cannot be classified as true leather because the preservation is superficial and requires constant reapplication of fats (Aikin 1833: 202). These might be thought of as mechanical processes for preserving hides and are reversible. True leather is preserved permanently -- the changes that occur are product of an irreversible chemical restructuring of the hide.

A final type is oil-tanned leather, known historically as *chamois*. This is achieved by saturating hides in certain oils, most commonly extracted from marine mammals like seals, which oxidize over time. This oxidation releases tanning agents

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39 Mineral tanning (tawing) is achieved by steeping hides in a solution of 3 parts salt to 12 parts alum for 15 minutes, then letting the hides dry. Tawed leather is noted for its pure white color, but has no resistance to water and is especially inclined to turn back to volatile skin when wetted. It has a very open grain texture and needs substantial stuffing with dressings like egg-yolk or oil. It use is retained today in the production of thin, supple glove leathers (Waterer 1986: 8; Stambolov 1969: 22; Reed 1972: 62).
able to have more profound effect on the preservation of the hide. Prehistoric oil tanned leathers might have been produced using substances such as brain, egg-yolk, and fat from the hide itself, creating a hydrophobic barrier which repels water. These practices can still be observed in use by First Nations tribes (Stambolov 1969: 11; Reed 1972: 66). In the sixteenth and seventeenth centuries, chamois buff leather was used extensively for military jerkins (Waterer 1981: 78).

**Fiber Structure**

The uniquely resilient properties of leather are given by its fibrous structure. Indeed, the many methods used to tan hides are all attempts to preserve the fibrous tissue found in the middle layers of an animal skin, called the *corium* (Waterer 1986: 7). As a microscopic examination of leather reveals [Figure 4.1], the hide is actually a tightly interwoven sheet of fibers. These fibers vary considerably in size, with larger fiber bundles branching off into countless smaller fibers, twisting and intertwining with neighboring fibers. The matrix of fibers is thus extremely resistant to bending and other stresses along any particular line or section. Moreover, stresses can be efficiently dispersed across the intertwined network and exhibit high abrasion resistance. Tanning processes preserve these characteristics of living skin as leather.

Embedded within the corium are a variety of smaller organ systems that compose the epidermis at large. These include hair shafts, sebaceous glands, and

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40 The flesh layer of hide is initially removed by tanners when preparing the hide for tanning. Once the leather has been fully tanned, it is returned to the currier who shaves off thin layers of the lower corium until the leather is an even thickness. Depending upon the final usage, the top grain layer might also be removed -- this provides a rough out look, where the frays of the corium layer are at the surface. This finishing practice is especially useful for hardwearing applications where scuffs and blemishes are not as easily accumulated.
veins, vital to the skin in living form [Figure 4.2]. While all mammal hides share these features, variations exist within a population and among species. Most notably, these include variations in total hide thickness, dimensions of the corium fiber bundles, and thickness of the topmost grain layer (Haines 2006: *Fiber Structure* 12). Contained organ systems such as hair follicles group themselves in different patterns from species to species, resulting in different surface appearances. These patterns can often be used to identify the species of origin of unknown leather.\(^4\) The directionality and density of fibers varies throughout the hide, resulting in regions that exhibit different physical properties. Overall, the direction of fibers in the corium layer will follow the direction indicated by the topmost grain observable at the surface. As [Figure 4.3] indicates, hide fibers radiate outward from the center of the spine and travel toward the edges in a predictable pattern. This central point of the hide is not only the thickest region, but also contains the greatest density of fibers. As the fibers travel outward, the hide decreases in thickness approaching the belly. At this point, previously maintained lines of fibers might be abandoned and a more random or undulating path is adopted. These peripheral regions of the hide are thinner and less densely packed with fibrils. They exhibit greater elasticity, but their lighter weight makes belly cuts less suitable for high impact or abusive applications.

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\(^4\) Microscopic cross-sections that reveal variations in thickness of the grain, corium, and flesh layers are useful when identifying mammalian leather, with most species (cow, goat, pig, etc.) having a distinguished appearance visible in this cross-section (Haines 2006: *Fiber Structure* 17; Reed 1972: 34).
Collagen

All mammalian skins are built from collagen proteins. Like all proteins, collagen is formed from chains of naturally occurring amino acids. In leather, these most essential amino acids are glycine, glutamic acid, and lysine [Figure 4.4]. When the polar and non-polar sides of chains are aligned, “the amino acids are linked together by covalent peptide bonding between the carboxyl of one amino acid and the amino group of an adjacent amino acid” (Haines 2006: Collagen 4). This bond coincides with the release of water in a condensation reaction, illustrated in [Figure 4.5]. Chains can be composed of up to 20 different amino acids and 1000 units, measuring roughly 300nm in length. Each chain is helical in structure, yet only comprises a single part of the collagen molecule. Collagen itself is made up of three distinct amino acid chains, twisting around each other in a triple helix pattern (Haines 2006: Collagen 5). This coil is held together by hydrogen bonds between groups in adjacent chains. Glycine, which accounts for 30% of amino acids found collagen, occurs at every third position along the chain. Its position is such that the small side chain of glycine projects into the center of the twisting molecules, bonding with the backbones of neighboring chains [Figure 4.6 and 4.7]. Thus a single fibril of a hide is formed. Due to the consistent chemical structure all collagen fibrils are built from, they are almost identical in diameter, regardless of species. However, the density of these fibrils in the corium varies considerably, even within a single hide. As detailed before, the tightest density of these fibrils may be found closest to the spine, with an

42 My specific understanding of the chemistry of collagen has been informed primarily by B. M. Haines, who wrote the chapter Collagen: the Leathermaking Protein in the larger reference volume on leather (Kite et al. 2006). Haines expounds the essential chemical properties that govern leather as a material in an accessible, yet detailed manner. I seek to outline some of these most necessary elements, though his own writings on the subject should be consulted for exacting detail.
overall decrease in density approaching the edges. This density of fibrils has a direct effect on the durability of the hide. The more fibrils employed to handle a load, the more effective that network is at redirecting and absorbing energy -- deceasing the likelihood of a fissure in the hide [Figure 4.8].

**Vegetable Tanning**

In its natural untanned state, the hide retains a great deal of water, stored within the collagen fibrils. Water is essential to the biological functions of the hide and its hydrating properties keep the skin supple, flexible, and stable. This moisture is likewise essential to the hide’s performance, allowing fibers to bend without cracking and slip by each other at a microscopic level when the animal moves. Early preservation techniques, such as slow drying, seek to extract this water from the corium layer, dehydrating the skin, but fail to preserve the pliability of the fiber matrix. While this process temporarily safeguards the hide against bacterial deterioration (defeated if the dried skin is rewetted), it is not without cost. Due to the bone-dry fiber structure, individual collagen fibrils are left brittle and weak. Where natural hydration once provided elasticity and resilience, its absence is a detriment to the hide’s performance. Thus, dried hides are liable to crack and splinter, degrading quickly with use and exposure. While pseudo-tanning techniques such or oil tanning seek to introduce fats into the corium layer, lubricating the fibrils and facilitating pliability, the eventual drying of these salves leaves the hide hard again.

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43 Untanned hides can in fact be quite stable and long lasting, as parchment attests, though they must be kept within specific storage conditions to have this life span (Covington 2006: 22).
Vegetable tanning, in contrast, seeks provide chemical and physical stability to the collagen fiber network via chemical bonds introduced between tanning agents and leather fibers (Davies 2006: 97). Tannins may be found in many plant species, particularly common in trees. Plant matter such as bark may be collected and processed, immersed in water, and steeped to create tanning solutions, commonly called tanning liquors. Hides exposed to these tanning liquors undergo a novel process called vegetable tanning. When soaked in tanning liquors for a prolonged period of time, the tannins serve to replace the structure water once offered in the living hide. As the hide dehydrates in the tanning liquor, phenolic tannin molecules are imparted into the fiber structure, forming hydrogen bonds with collagen proteins (Covington 2006). The tannins effectively support the hide in the absence of water. Tanning is a permanent process, far more stable and enduring than pseudo tanning preservation techniques. For these reasons, vegetable tanned hides may finally be classified as leather, a superior state of hide which exhibits the desirable properties of durability, water resistance, and most uniquely mildew resistance.

The success and quality of any tanning operation is dependent upon the thoroughness of the tanning throughout the hide, penetrating even the innermost fibers of the corium layer. While medieval vegetable tanning operations were carried

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44 Within the last 130 years, chrome tanning has come to dominate the leather industry, surpassing the use of vegetable tanned leathers. It must be realized, however, that the technology required to carry out chrome tanning is entirely modern relative to medieval technology. Chrome tanning thus does not figure prominently in my consideration of tanning processes, it being non-essential to the conditions for cuir bouilli.

45 Tannins exist in plant and tree species around the globe. While the occurrence of tannins in plant matter is nearly universal, their concentration and specific properties can vary greatly from species to species. Certain species lend themselves more readily to providing the raw organic material necessary for quality leather production (Harvey 1921). As explored earlier, oak was the widely preferred tanning material in the Middle Ages and Renaissance.
out in earthen pits or barrels, the process today has become far more industrialized. Previously, bark and other organic matter needed to be steeped for weeks, months, or longer to produce tanning liquors with the desired tannin concentration necessary for hardwearing leather. The untanned hides then needed to be immersed in these liquors as long as 5 years for some specialty leathers (Stambolov 1969: 17). During this time, they would be rotated periodically to ensure even exposure.

Modern vegetable tanning uses specialized technology to expedite this process tremendously, all while ensuring a consistent and durable product. In the early twentieth century, procedures were developed to manufacture tanning extracts. These extracts are far more concentrated with tannins than medieval tanning liquors and able to penetrate the corium structure more rapidly and completely. This chemical advantage is also paired with the mechanical tanning advantage of revolving drums. These massive drums turn the hides vigorously, letting them tumble over themselves and with tanning extracts to hasten the penetration and absorption of tannins. Thus, quality full-grain leathers can be produced from raw hide in a matter of days where it took years in historical leather manufacture. Nevertheless, the essential effects of tannins on hide durability remain consistent, though applied differentially.

46 The full development and chemical processes of tanning extract manufacture has been documented by Harvey (1921). This development also revealed the existence of two categories of tannins: hydrolysable tannins and condensed tannins.

47 In addition to revolving drums, many other machines were introduced to the leather manufacturing industry during the twentieth century. These included spiral-bladed fleshing machines, shaving machines, and rollers that greatly expedited the process of leather production. The role of the currier was absorbed, in this mechanization (Thomson 2006: Manufacture of Leather 75).
**Shrinkage Temperature**

The collagen fiber structure of leather also possesses a distinct trait known as *shrinkage temperature*. As the name implies, shrinkage temperature refers to the contracting of collagen fibrils when exposed to a certain heat in the presence of water. For untanned hides, this occurs at roughly 55-60ºC, depending upon the particular hide. Various tanning and preservation treatments, however, alter the precise point at which this will occur. For vegetable tanned leathers, those most commonly used during the middle ages and what I will be using for the purposes of my experiment, shrinkage temperature occurs closer to 75-85ºC.

Shrinkage occurs due to the breakdown of hydrogen bonds between collagen fibers, primarily responsible for holding the matrix together. When the energy exerted on these bonds, in the form of heat, exceeds that of the bond strength, it causes the individual collagen chains to contract. When no longer bonded, collagen chains exhibit great elasticity and shrink rapidly. The tannins are partially melted, and redistribute themselves within the fiber network. They are fixed in place again once cooled. Only the remaining covalent bonds keep the resulting structure together (Haines 2006: *Collagen* 9). This process is irreversible, causing a permanent change in the leather’s molecular structure and consistency. All original fibers remain, yet they are distributed across a smaller area. Thus, there is an overall increase in fiber density in leather that has been subjected to shrinkage temperature. This heightened density causes shrunken leather to be much stiffer than its pre-shrunken state.

Depending upon how long the leather is allowed to experience shrinkage conditions, it may contract differentially. This is influenced by the specific fiber
structure of a piece of leather and the tanning agents used in its production (Haines 2006: Collagen 10). Brief exposures will shrink the leather only slightly in total area and cause a less extreme increase in fiber density. These samples might retain a degree of flexibility. Prolonged exposure, however, can shrink the leather considerably -- even to half its original size. Such a dramatic increase in fiber density can produce rigid plates of leather, unable to be bent and lacking all suppleness that characterized it previously. These leathers that have been shrunken drastically are liable to crack and shatter upon impact, rather than deforming temporarily and springing back into shape. As such, there exists a great deal of variability in the final properties piece of shrunken leather might exhibit. While too little exposure to shrinkage conditions might have negligible effect on the leather, over exposure of the shrinkage mechanism can cause weakness, resulting in a brittle and fragile piece of hardened leather. Within this spectrum, there may also be a range that balances desirable properties of fiber density, rigidity, and plasticity.

Shrunken leather can behave in a manner not unlike that of modern polymers. While hot and wet, it can be molded to forms, which set when dried. Such processes, it is believed, could very well have been applied to the craft of armor manufacture during the experimental centuries preceding metal plate armor. Serving as a preliminary model for armors that would supersede it, the unique durability of leather was exploited with this intent. It is therefore my goal to experiment with the shrinkage temperature mechanism in a controlled setting, isolating the variables affecting this process. Within this spectrum, I believe effective mechanisms of hardening leather intended for use as plate armor might be revealed. These might
exemplify the general properties of *cuir bouilli* plate armor as it would have existed in a medieval setting.
Chapter 4 Figures:

**Figure 4.1:** Cross section of leather made from mature cattle hide. Note the branching and intertwining bundles of collagen fibers (Haines 2006: *Fiber Structure* 13).

**Figure 4.2:** An illustrated cross section with embedded organelles and sections identified (Haines 2006: *Fiber Structure* 12).
**Figure 4.3:** General direction of collagen fibers throughout the hide (Haines 2006: *Fiber Structure* 20).

**Figure 4.4 (left):** Glycine and Glutamic, two of the most common amino acid chains in collagen fibers (Haines 2006: *Collagen* 4)

**Figure 4.5 (right):** Peptide bonding between amino acids (Haines 2006: *Collagen* 5).
Figure 4.6 (left): Helical chains of amino acids twisting together to form collagen fibrils (Haines 2006: Collagen 6).

Figure 4.7 (right): Hydrogen bonding between neighboring chains of amino acids, occurring at every third position in the helix (Haines 2006: Collagen 6).

Figure 4.8: Cross section of a single collagen fiber, showing elementary fibrils grouped together to form a larger fiber (Haines 2006: Collagen 10).
Chapter 5: Preparing Cuir Bouilli Samples

This chapter explains my methods for preparing all cuir bouilli samples. I will explain the 30 sample group which I have prepared and the reasoning for each choice. All variables being manipulated will be addressed, including time, temperature, and further treatments such as baking and wax. Whenever possible, the exact historical rationale for each decision will be addressed.

To test a wide range of effects these identified variables have on leather, I have produced 30 unique samples. Each sample was assigned a specific treatment, or recipe, inspired by historically grounded leather working techniques. These recipes were meant to emulate methods which might have been used to produce rigid cuir bouilli plates, best used as protective armor. While every attempt has been taken to replicate materials as they would have appeared in a medieval context, there are certain difficulties which must accept near substitutes. Each of these dissonant features will be addressed, and the remedy for them in my experiment justified.

Leather Selection

For my source leather, I used leather tanned by Wickett and Craig, one of the oldest operating tanneries in the United States, founded in 1867. Their leather is still tanned using exclusively vegetable tanning methods. Chrome tanning and is not practiced in this facility (Wickett & Craig, 2010). Although the scale of production is vast compared to historic models, and the infrastructure is technologically more sophisticated, the leather produced is fundamentally the same as that which would have been produced during the middle ages. The tannins fill the hide, preserving it, in
a chemical process that has not changed substantially since its invention. This vegetable tanned state is essential for shrinkage effects to behave in a predictable way and to best emulate the material used in a medieval setting.

The leather I used for my project optimized the possibility for objective study of each recipe. Modern vegetable tanning methods are extremely refined, especially when compared to historic models. The leather produced by manufactures such as Wickett & Craig undergoes a multitude of quality control checks to before it sold, with the result that a reliable product can be produced from batch to batch. Earlier historic vegetable tanning operations that utilized less controlled tanning pits, allowed more room for inconsistent patches of tannins to be dispersed across the hide. This would produce a lumpy hide, with patches tougher than others. Modern tanning methods safeguard against these manufacturing defects. With a more stable platform to apply each recipe, the most clear reading of its effects of each could be obtained. The opportunity to use modern vegetable tanned leather maintains the basic chemical principles that define *cuir bouilli* in a more predictably reactive medium. 48 Perhaps most importantly, shrinkage temperature, a crucial property of vegetable tanned leather, can be manipulated as it would have in a medieval setting. Thus, modern vegetable tanned leathers, in addition to being accessible in large volumes, provide an acceptable substitute for the leather that would have predominated medieval material culture.

48 Of course, a truly accurate historical sample of leather would be interesting, but problematic. Producing a vegetable tanned hide that replicates medieval leather exactly is an experimental archaeology problem in itself. Obtaining a quantity substantial enough for this project would be difficult, logistically. I came to the conclusion to use leather from Wickett and Craig through a friend at DeSantis Holster. Desantis is a manufacturer of leather gun holsters able to sell the leather to me at the right price. They were also able to cut each piece into the 28x29cm squares that I used.
For my samples, 7-8oz leather was used, with each piece cut to 27.94cm by 29.21cm per side (11 by 11.5 inches) [Figure 5.1]. 80 pieces were ordered to complete this process, offering a handful of opportunities to reproduce samples that were perhaps flawed by my own errors or unacceptable for other reasons. Before any samples were prepared, these pieces were measured to ensure that they met the outlined standards. This was done to maintain a consistent foundation for each recipe and to ensure the accuracy of measurements taken after each sample was prepared. During this time, any inconsistencies or anomalies observed in the hide were also noted. Fortunately, given the quality of Wickett & Craig’s leathers, very few samples had identifiable defects. These particular pieces were not used for the final sample group.

Each of the 30 was assigned a unique preparation procedure, found in the table below [Table 5.1]. This group broadly encapsulates the three most compelling techniques for manufacturing cuir bouilli: inducing shrinkage temperature while immersed in water, inducing shrinkage temperature during baking, and ‘stuffing’ the hide with beeswax. As the chart details, key variables were manipulated incrementally, increasing time, temperature, and further treatments in a predictable manner. Each sample was meant to build upon previously explored variables. The process was designed so that the properties observed in any particular sample could be directly compared to samples with similar treatments. For example, Sample 14 can be readily compared to Sample 5, revealing the marginal effect baking had in this instance. Unique identifiers were assigned to each sample which signal essential

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49 In leather measurements, 1oz refers to 1/64th of an inch. Thus, 7-8oz leather is approximately 2.778-3.175mm thick.
information about how it was prepared. Thus, Sample 14 with an identifier of 55.60.1.0 can easily be recognized as having been immersed in 55°C water for 60 seconds, baked at 95°C until dry and not given a beeswax treatment. I have ordered enough materials so to prepare each recipe twice.

Sample Group

Table 5.1: Cuir bouilli samples with unique treatment prescriptions.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Identifier</th>
<th>Water Temperature</th>
<th>Time Immersed</th>
<th>Baking</th>
<th>Wax</th>
<th>Baking + Wax</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>15.30.0.0</td>
<td>15°C (Cold)</td>
<td>30 sec.</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S2</td>
<td>15.60.0.0</td>
<td>15°C</td>
<td>60 sec.</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S3</td>
<td>15.90.0.0</td>
<td>15°C</td>
<td>90 sec.</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S4</td>
<td>55.30.0.0</td>
<td>55°C (Warm)</td>
<td>30 sec.</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S5</td>
<td>55.60.0.0</td>
<td>55°C</td>
<td>60 sec.</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S6</td>
<td>55.90.0.0</td>
<td>55°C</td>
<td>90 sec.</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S7</td>
<td>100.30.0.0</td>
<td>100°C (Hot)</td>
<td>30 sec.</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S8</td>
<td>100.60.0.0</td>
<td>100°C</td>
<td>60 sec.</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S9</td>
<td>100.90.0.0</td>
<td>100°C</td>
<td>90 sec.</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S10</td>
<td>15.30.1.0</td>
<td>15°C</td>
<td>30 sec.</td>
<td>95°C</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S11</td>
<td>15.60.1.0</td>
<td>15°C</td>
<td>60 sec.</td>
<td>95°C</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S12</td>
<td>15.90.1.0</td>
<td>15°C</td>
<td>90 sec.</td>
<td>95°C</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S13</td>
<td>55.30.1.0</td>
<td>55°C</td>
<td>30 sec.</td>
<td>95°C</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S14</td>
<td>55.60.1.0</td>
<td>55°C</td>
<td>60 sec.</td>
<td>95°C</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S15</td>
<td>55.90.1.0</td>
<td>55°C</td>
<td>90 sec.</td>
<td>95°C</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S16</td>
<td>100.30.1.0</td>
<td>100°C</td>
<td>30 sec.</td>
<td>95°C</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S17</td>
<td>100.60.1.0</td>
<td>100°C</td>
<td>60 sec.</td>
<td>95°C</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S18</td>
<td>100.90.1.0</td>
<td>100°C</td>
<td>90 sec.</td>
<td>95°C</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S19</td>
<td>15.30.0.1</td>
<td>15°C</td>
<td>30 sec.</td>
<td>N/A</td>
<td>Beeswax</td>
<td>N/A</td>
</tr>
<tr>
<td>S20</td>
<td>15.60.0.1</td>
<td>15°C</td>
<td>60 sec.</td>
<td>N/A</td>
<td>Beeswax</td>
<td>N/A</td>
</tr>
<tr>
<td>S21</td>
<td>15.90.0.1</td>
<td>15°C</td>
<td>90 sec.</td>
<td>N/A</td>
<td>Beeswax</td>
<td>N/A</td>
</tr>
<tr>
<td>S22</td>
<td>55.30.0.1</td>
<td>55°C</td>
<td>30 sec.</td>
<td>N/A</td>
<td>Beeswax</td>
<td>N/A</td>
</tr>
<tr>
<td>S23</td>
<td>55.60.0.1</td>
<td>55°C</td>
<td>60 sec.</td>
<td>N/A</td>
<td>Beeswax</td>
<td>N/A</td>
</tr>
<tr>
<td>S24</td>
<td>55.90.0.1</td>
<td>55°C</td>
<td>90 sec.</td>
<td>N/A</td>
<td>Beeswax</td>
<td>N/A</td>
</tr>
<tr>
<td>S25</td>
<td>100.30.0.1</td>
<td>100°C</td>
<td>30 sec.</td>
<td>N/A</td>
<td>Beeswax</td>
<td>N/A</td>
</tr>
<tr>
<td>S26</td>
<td>100.60.0.1</td>
<td>100°C</td>
<td>60 sec.</td>
<td>N/A</td>
<td>Beeswax</td>
<td>N/A</td>
</tr>
<tr>
<td>S27</td>
<td>100.90.0.1</td>
<td>100°C</td>
<td>90 sec.</td>
<td>N/A</td>
<td>Beeswax</td>
<td>N/A</td>
</tr>
<tr>
<td>S28</td>
<td>15.60.1.1</td>
<td>15°C</td>
<td>60 sec.</td>
<td>94°C</td>
<td>Beeswax</td>
<td>&amp;</td>
</tr>
<tr>
<td>S29</td>
<td>55.60.1.1</td>
<td>55°C</td>
<td>60 sec.</td>
<td>94°C</td>
<td>Beeswax</td>
<td>&amp;</td>
</tr>
<tr>
<td>S30</td>
<td>100.60.1.1</td>
<td>100°C</td>
<td>60 sec.</td>
<td>94°C</td>
<td>Beeswax</td>
<td>&amp;</td>
</tr>
</tbody>
</table>
As detailed explored in Chapter 4, shrinkage of vegetable tanned leather occurs at ~75-85ºC, depending upon the particular hide. My samples took varying, incremental approaches to inducing these shrinkage properties. A stepped program of times and temperatures was employed. The Samples S1-S3 prescribed immersion of each piece of leather in 15ºC water, cool to the touch. These samples were immersed for 30, 60, and 90 seconds respectively and were not subjected to further treatment such as baking. 15ºC water is well below the identified shrinkage temperature -- it was not expected that these samples would contract in a meaningful way. Rather, they represented the absolute minimal procedure when crafting *cuir bouilli*. Furthermore, they served as ready baseline comparisons for when additional treatments were added, making the marginal strength differences between treatments easily identifiable.

Samples S4-S6 were treated similarly, but at a higher temperature. These samples were immersed in water at 55ºC, warm to the touch and approaching shrinkage temperature, yet still well below the actual value. Again, they were immersed for 30, 60, and 90 seconds and were not subjected to further treatment. These samples were meant to address the possibility of warm water as an essential component of the *cuir bouilli* preparation process. Waterer (1981) promoted this temperature range as the absolute maximum for producing functional *cuir bouilli*. Their failure to reach true shrinkage temperature, however, again makes them unlikely to have profound hardening properties. Like other baseline samples, these served as reference points for comparison to other methods.
With Samples S7-S9, shrinkage was finally induced during the initial immersion in water step. At 100°C, boiling water exceeded these requirements and always resulted in measurable contraction of the leather. At these higher temperatures, timing was a crucial measure. Hot water is able to penetrate leather more quickly and promote shrinkage changes more rapidly. The longer each piece was left immersed, the more extreme the shrinkage effect and greater potential density. I have selected times ranges that explore the scaled effect different lengths of immersion have on shrinkage and density. 30 seconds was considered a brief immersion. The middle timing range of 60 seconds doubled the time each piece is soaked in water. Depending upon the temperature this is paired with, potentially drastic changes in the hide structure may occur, directly affecting their performance in the armor tests to follow. The final time range prescribed was 90 seconds, again adding 30 seconds to the previously explored range. After 90 seconds, especially at higher temperatures, shrinkage should have taken full effect, penetrating the hide thoroughly and inducing any contractions. Furthermore, earlier experiments that sought to understand the effects of boiling water on leather have shown that this method is ineffective once it surpasses a certain point. Prolonged exposure to boiling water is known to destroy the material quality of the hide, breaking down the fibrous structure and reducing the leather to a gelatinous mass (Waterer 1981: 62). Limiting exposure to only 90 seconds discourages these detrimental effects from taking hold while still ensuring that shrinkage can occur naturally and thoroughly.

I have chosen to treat samples at 100°C (boiling) rather than the minimum shrinkage temperature of 80°C for a couple reasons. First and foremost is to address
the literal interpretation of the phrase *cuir bouilli*. Despite its dismissal by Waterer, there is not enough data to persuade me that it is an irrelevant treatment method, especially when artists like Lingwood uphold its effectiveness. The data collected from my tests might conclusively demonstrate that boiling is impotent, or that there is potential for this method. Moreover, this higher temperature was also chosen to exaggerate the contrast between variables. By bracketing the threshold of shrinkage temperature, I believe, trends in performance will be more pronounced and clearer distinctions made between treatment methods.

Following the completion of all water immersion or boiling steps, including drying, the leather was baked at 95°C for 30 minutes, a temperature and time range that has been appropriated from Rex Lingwood’s production methods (Lingwood 1980: 63). This temperature was hot enough that it could induce shrinkage, yet mild enough that it would not sear the hide itself. Rather than drying slowly by air, as unbaked samples were, these baked samples dried far more rapidly in the warm environment. This exposure to temperatures that exceed the shrinkage threshold caused the leather to contract, increasing the fiber density. This decision was also influenced by Cameron’s investigation into the use of mild heat. Her findings determined that baking at lower temperatures is largely ineffectual. Instead, Cameron identified ~95°C as the most effective hardening temperature for baked samples, corroborating Lingwood’s methods (Cameron 2000: 230).
Preliminary Samples

In preparation for the actual cuir bouilli sample production, I performed a number of smaller scale experiments. Four smaller pieces were cut from a single piece of test leather, identical to that used for all final samples. These four pieces each measured 14cm by 14.6cm initially. They served as procedural models, revealing aspects of the process not obvious at the outset of my experimental design and prompted some retuning of the methods I used for my full scale cuir bouilli sample group. Observations from each sample are recorded as follows, along with the implications they had on the experimental procedure.

Preliminary Sample 1, Sample 5, 55.60.0.0

This sample was my first hands on experience with preparing cuir bouilli. For this first sample, I chose a simple recipe, requiring only one step to prepare: immersion in 55ºC water for 60 seconds. When the water had reached a stable temperature, I dropped the leather in the pot, started my timer, and observed its effects. Immediately, the leather darkened in color as the water soaked the outer surfaces. Additionally, tiny fountains of bubbles emerged from the leather, hissing as they rose to the surface. It became apparent to me in this instance that these bubbles indicated saturation of the leather. So long as bubbles continued to rise from the leather, the air within the leather was still being replaced by water. As the bubbles slowed nearing the 30 second mark, the leather sunk toward the bottom of the pot. I agitated the water to keep the leather from being burned on the hotter bottom surface, keeping it suspended within the warm water. When 60 second mark was reached, the leather was removed from the pot and allowed to dry naturally at room temperature.
After 12 hours left to dry, the leather had curled slightly with the top-grain on the inside of this curve. While the leather did not appear to have hardened considerably, not surprising since shrinkage temperature was not achieved, two important observations were made. The first concerned saturation of the leather. Since the leather was dry when it first entered the pot, a great deal of the 60 seconds was spent allowing the water to saturate the fiber matrix. In order for any hardening effects to take hold, the leather must be fully saturated already, thus, this could not occur until relatively late in the test process. To observe the effects of each recipe in the most direct manner possible, this initial saturation time could be expedited. Thus, by briefly soaking each piece of leather in room temperature water before immersion in any warmer water treatment, the full effect of the warm immersion could be observed without the time squandered waiting for an initial saturation to occur. The second crucial observation made concerned the curling of the leather as it dried. In order for the armor tests to be performed in a consistent manner, each sample of leather must be uniform in shape. Thus, the form of the leather must be corrected as it dries following any treatment. So long as the leather was still wet, its shape had not been permanently set and it was still in danger of curling into an unusable form. All samples need to be weighted to define their shape until thoroughly dry.

**Preliminary Sample 2, Sample 14 (version 1, 95°C), 55.60.1.0**

This second sample is very much like the first, but with a handful of distinct procedural differences. As the identifier indicates, this sample was subjected to a baking drying procedure. However, the initial preparation of this sample also differed from the first, taking advantage of observations made during this initial test. As noted
earlier, full saturation of the leather is necessary for shrinkage conditions to take effect. This sample was pre-soaked in room temperature water for 3 minutes prior to its immersion. This let the warm water take more immediate effect on this test piece. Like the first sample, this Preliminary Sample 2 was left in the warm water for only 60 seconds. Unlike, the first, however, this sample was baked in an oven at 95°C, exposing the leather to shrinkage temperatures. After 30 minutes, the sample was removed from the oven and allowed to dry completely in the air. 12 hours later, the leather, which emerged from the oven quite flat and free from physical distortions, was curled slightly -- again indicating that weight was needed to maintain shape. Despite the leather not shrinking considerably in size, it was tougher to the touch. Attempts to bend and twist this piece were met with much more resistance than the unbaked sample which preceded it. This marginal difference in strength could therefore be attributed to the oven baking treatment, the most significant variable which differentiated the two.

**Preliminary Sample 3, Sample 14 (version 2, 177°C), 55.60.1.0**

This third preliminary sample again built upon the observations made in previously explored samples. Its preparation procedure was identical to that of Preliminary Sample 2, with one distinct difference. Again, this piece was pre-soaked, then immersed in 55°C water for 60 seconds. Immediately following this immersion, it was baked in the oven. However, this piece was baked at 177°C for only 10 minutes -- nearly double the temperature and only one third the time of Preliminary Sample 2. The differences in final product were considerable. Around the 6 minute mark in the oven, this piece began curling. By the end of the 10 minute bake, the leather had
curled almost to a full semi-circle. In order to correct this shape, the piece was dried under a wooden cutting board. The leather was dried completely over night. Unlike Preliminary Sample 2, baked at 95ºC, this piece shrunk by about half a centimeter in both dimensions. Moreover, this piece was far more rigid than Preliminary Sample 2. While it could be bent by hand, it required far more force and sprung back into its earlier shape almost immediately. Further exploration of its elasticity was met with failure. A crack developed through the top grain and upper corium.

**Preliminary Sample 4, Sample 8, 100.60.0.0**

The final preliminary sample I produced was meant to emulate Sample 8 on the table. This sample was pre-soaked before being immersed in 100ºC (boiling) water for 60 seconds. This temperature level exceeded shrinkage temperature and dramatic results were expected. Within only 15 seconds of exposure to the boiling water, the leather began to curl inward on the top grain side. After 30 seconds, the leather had twisted itself into a tight roll. Following the immersion, this piece was carefully unrolled, but not stretched, and left to dry under a weighted piece of wood. The leather darkened to a deep brown and shrunk substantially in size, over 2 centimeters in either direction. Unlike all other preliminary samples that retained a degree of elasticity, Preliminary Sample 4 was very rigid. Rather than bending with pressure, it cracked through the top grain and entire corium, breaking the sample in two. This literal *boiled leather* had shockingly different properties from the natural vegetable tanned leather. While this sample was undoubtedly the hardest produced thus far, it was also the most brittle. This balance of rigidity and elasticity was more thoroughly explored in the 30 final samples.
Cuir Bouilli Preparation Procedure

Water Immersion Steps:

*Samples with 15°C Immersion*

- Measure sample before immersion. Confirm that these measurements match desired specifications. Examine the leather for visible deformations or abnormalities. If major defects are identified, this piece of leather should not be used.
- Fill an appropriately sized vessel with water and measure temperature. The vessel should be deep enough to easily immerse the entire sheet of leather. It should also be wide enough to fit the leather without bending [Figure 5.2]
- If the temperature deviates from the desired 15°C, add cold or hot water as needed to adjust.
- Make sure a stopwatch is at the ready to track time.
- When the water has been prepared, drop the dry, vegetable tanned leather in the 15°C water. The leather will float at first, then sink to the bottom as full saturation is achieved. Ensure water coats the entire piece to encourage thorough and even saturation [Figure 5.3].
- When the desired time has been reached (30, 60, or 90 seconds), remove the leather from the vessel.
- Blot dry using towels.
- Bring leather to drying table to dry at ambient temperatures. Refer to DRYING STEPS.

*Samples with 55° or 100°C Immersion*

- Measure sample before immersion. Confirm that these measurements match desired specifications. Examine the leather for visible deformations or abnormalities. If major defects are identified, this piece of leather should not be used.
- Fill an appropriately sized vessel with water and measure temperature. The vessel should be deep enough to easily immerse the entire sheet of leather. It should also be wide enough to fit the leather without bending. This vessel will be used for the presoak.
- Fill a large pot with water. Again, this vessel should be able to easily immerse the entire sheet of leather.
- Heat the pot of water to the desired temperature, either 55° or 100°C, using a quality thermometer to ensure accuracy. When this temperature has been achieved, decrease the burner heat to maintain a stable temperature [Figure 5.4].
- Before immersion in the heated water, pre-soak the sheet of leather in the first basin. Keep the leather fully submersed for 90 seconds, or until bubbles cease to rise from the surface -- indicating full saturation.
- When the pre-soak has been completed, transfer the leather to the heated water. Start the stopwatch timer.
The leather will sink to the bottom of the pot. Using tongs or another stirring implement, agitate the water and leather to keep it from touching the bottom of the pot, suspended within the water [Figure 5.5].

When the desired time has been reached (30, 60, or 90 seconds), removed the leather from the vessel [Figure 5.6].

Blot dry using towels.

Dry leather at ambient temperatures. Refer to DRYING STEPS.

Drying Steps:

Locate a flat area where leather samples can be laid to dry. This surface will define the flat shape, so ensure it is free from debris that could imprint into the surface.

Samples that have been immersed at 15ºC or 55ºC will be relatively flat upon removal from water immersions or baking. Lay them top grain side down on the flat surface.

Using wooden boards, weigh down the edges of each sheet of leather to prevent curling as the sample dries [Figure 5.7].

Samples that have been immersed in 100ºC water will curl considerably during the immersion and baking process. They must be carefully rolled out and clamped down with boards and additional weights. When unrolling the boiled sample, avoid stretching the leather whenever possible -- shrinkage is a vital measurement that should not be obscured [Figure 5.8].

After 3-5 hours, the leather will have dried partially on the flesh side. Flip each piece and replace the boards and weights. It is important that the leather is under pressure for the entire drying process. It can curl at any point if still wet.

Continue flipping samples every few hours until completely dry.

After 24 hours, most samples will be dry and stable. They can now be removed from the drying table and stacked. It is advisable, however, to keep some moderate pressure on the stack of samples, even if only a heavy book, to prevent curling and retain the flat shape.

Baking Steps:

Heat the oven to 95ºC (203ºF) and let it rest at this temperature for an hour to ensure even heating. Verify the temperature is accurate using an oven thermometer and adjust accordingly.

Cover the oven rack in with a sheet of aluminum foil and punch holes every 2 cm along it. The foil protects the leather from being seared by the metal oven rack, while holes allow air and heat to move through it [Figure 5.9].

Fill an appropriately sized vessel with water. The vessel should be deep enough to easily immerse the entire sheet of leather. It should also be wide enough to fit the leather without bending. This vessel will be used for the presoak at 20ºC. Adjust to achieve this temperature.
Soak the desired piece of leather in water for 90 seconds. Blot dry with a towel, but do not scrub the surface. The leather should still be entirely saturated when placed in the oven.

*Samples with 15°C and 55°C immersion*
- Put the leather in the oven, top-grain side down, and shut the oven door. Start your timer.
- After 10 minutes, flip the leather to the flesh side down and rotate the front side to the back (A full flip).
- After another 10 minutes (20 total), flip back to the top grain side down.
- Flip again after 5 minutes, and again 5 minutes after that. (30 minutes total. 10-10-5-5 minutes per side).
- After 30 minutes have passed, remove the leather from the oven.
- Bring the baked leather back to the drying table and follow standard drying procedure.

*Samples with 100°C immersion*
- Put the leather in the oven, top grain side down.
- Place a second oven rack on top of the piece of leather. The oven rack should not be resting on a guide rail -- all weight should be on the leather itself. Previously boiled samples are liable to curl aggressively when baked. This second rack sandwiches the sample, preventing severe deformation [Figure 5.10].
- After only 5 minutes, flip the leather to the flesh side down. If it has curled, you may gently flatten it by hand. Be sure to replace the second, top rack again to minimize curling.
- Flip the leather after another 5 minutes using the above procedure. Flip the leather once more after the final 5 minutes to complete the baking process.
- After 15 minutes (5-5-5) have passed, remove the leather from the oven.
- Bring the baked leather back to the drying table and follow standard drying procedure.

**Waxing Steps:**
- Using a double boiler, melt 6 pounds of pure, organic beeswax. The vessel containing the wax should be big enough to accommodate each piece of leather, fully immersing it in wax [Figure 5.11 and 5.12].
- Beeswax melts at 64°C and has a flash point of 204°C. The double boiler will ensure that the beeswax cannot surpass 100°C in temperature, providing safe working conditions.
- When the beeswax has melted evenly, with no solid chunks remaining, carefully lower the desired piece of leather into the wax. Let it sit fully immersed and start your stopwatch.
Bubbles will rise from the leather and it will darken in color, much like being immersed in water, but at a slower rate. The darkened areas of the leather indicate the fiber structure has been fully saturated with wax while lighter areas indicate wax sitting on the surface [Figure 5.13].

When the leather has been fully saturated with wax, generally after 45-55 seconds, remove it from the wax and allow the excess to drip off for 60 seconds. Allow the leather to dry following standard drying procedure. As the wax, cools to 64°C, it will harden considerably and set the form permanently.

Sample Descriptions

Samples S1-S3

Samples S1-S3 were treated in 15°C water for 30, 60, or 90 seconds, respectively. These treatments were minor, to say the least. Water at 15°C was cold to the touch and had no capacity to shrink the leather. Nevertheless, this was a necessary sample group for understanding the full range of effects water immersion has on leather. Because these treatments (particularly S1 immersed for only 30 seconds) were so mild, they served as a control or baseline. The leather was relatively unchanged from its pre-immersed state, allowing the opportunity to measure the effectiveness of plain vegetable tanned cowhide, the raw material needed for any cuir bouilli production. Curiously, as the later measurements revealed, these samples showed evidence of minute shrinkage, no more than 2mm in either dimension and nearly insignificant for all practical purposes. Such minor changes in dimensions do not signify serious shrinkage of the overall fiber network. When dry, these samples feel no different to the touch than untreated samples of leather.

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50 Individual photographs of Samples S1a-S30a and S1b-S30b may be found in [Figures 5.14 – 5.73] and should be consulted throughout the descriptions that follow.
**Samples S4-S6**

Samples S4-S6 were treated much like S1-S3, the difference being an immersion in water at 55°C rather than 15°C. This temperature, meant to be representative of the middle range of *cuir bouilli* production via water immersion, approximates the theories held by John Waterer, who believed that warm, not hot water, was the most effective approach. Again, 55°C was well below the threshold of shrinkage temperature, the main mechanism which has been proposed as crucial to *cuir bouilli*. As the following measurements confirmed, no significant shrinkage occurred during this process. Samples shrunk to a lesser extent even than S1-S3. Furthermore, the leather did not darken in color as a result of this treatment. Since darkening is often a signifier of shrunken leather, caused by the greater density of hide fibers, it can be confirmed that shrinkage did not occur in a meaningful way. When dry, these samples were slightly more rigid and resistant to bending than the three that preceded it. Obviously, this qualitative measure of hardness means little when defining the effectiveness of a sample, but may be indicative of other alterations that occurred during the immersion process. As Waterer proposed, the absence of natural oils and lubricants in leather can result in stiffness. I therefore believe that this slight increase in rigidity may have been due to the sapping of lubricants from the leather. The warm water was able to break down these compounds more effectively and dehydrate it, manifested as stiffness.

**Samples S7-S9**

Samples S7-S9 were the most literal interpretations of *cuir bouilli*. These samples were subjected to an immersion treatment in 100°C (boiling) water for 30,
60, and 90 seconds. While other samples emerged from their soaking treatments very much resembling their untreated state, S7-S9 were markedly different. After being plunged into the boiling water, a method endorsed by artisans such as Lingwood, the leather exhibited rapid transformation. With all samples, rapid shrinkage started to occur within 20 seconds of exposure to the boiling water. As the samples shrank, they contorted in shape, wrapping themselves into a tight roll until maximum shrinkage was achieved. Once removed from the boiling water, each sample needed to be carefully unrolled to correct this shape and ensure an even testing surface. After drying, these samples were measured, revealing shrinkage of up to 50%. This profound shrinkage produced samples that were indeed harder than the leather it started as. All samples that were boiled, including those that follow, are rigid. They resisted bending in any direction and when tapped on resonated more like wood. Of course, further tests were needed to confirm that this superficial hardness translated into a more effective *cuir bouilli* armor.

**Samples S10-S18**

Samples S10-S18 introduced a baking procedure to the *cuir bouilli* preparation process. These pieces were initially similar to S1-S9. The baking which followed was a separate process, taking place after the initial water immersion step was dried and completed. Samples which were baked have been resaturated, then dried rapidly in an oven at 95ºC. Due to the drastic shrinkage previously boiled samples had already undergone, they were only baked for 15 minutes instead of the standard 30. This necessity was discovered after some boiled samples were baked for the standard 30 minutes, causing uncorrectable warping and brittleness. They bear
minimal shrinkage due to the baking process, ranging from one to three centimeters at most. Nevertheless, baked samples were notably more rigid than those treated using only water immersion steps. Following Lingwood and Cameron’s baking temperature recommendations, the drying was expedited and shrinkage of the leather’s collagen fibers was promoted. Thus, the fibers were compacted, potentially translating into appreciable armor benefits.

**Samples S19-S27**

Samples 19-27 again introduced a step to the cuir bouilli preparation process. This step attempted to increase the strength of the leather with the addition of beeswax. These samples also began the preparation process akin to S1-9 with water immersion treatments. Following this, each sample was dipped in hot, melted beeswax prepared in a double boiler. Once placed in the beeswax basin, samples were left fully immersed until saturated. This was indicated by the gradual darkening of the leather’s surface as beeswax penetrated the collagen network, coating each fiber. The eventual lack of bubbles rising from the leather’s surface suggested that all air trapped in the leather had been replaced by wax. After 50-60 seconds in the hot wax, full saturation was generally achieved. The sample was removed and excess wax was allowed to drip off. When an even surface coating had been obtained, the samples were left to dry following standard drying procedure.

The beeswax solidified very quickly. When the wax reached 64°C, it hardened and set the shape of the leather sample. While minute pockets of air occupy space in the fiber network of untreated leather, beeswax filled in these pockets and added mass to the sample. Thus, while the leather retained its original dimensions, the addition of
beeswax throughout increased the overall density of the sample, potentially translating into a functional armor. All samples that were treated with beeswax exhibited dramatic hardening. The process seemed to take a more pronounced effect on samples that had not been boiled previously. Since the boiled samples had already been shrunk considerably, less air naturally occupied these samples, offering less room for the beeswax to replace it and add hardening effects. The rigidity offered by beeswax did not make the leather brittle, a problem that frustrated boiled samples. Bending a waxed sample (which had not been boiled previously) was met with an elasticity, quickly springing back to the defined shape after being momentarily deformed. The following tests were used to determine whether this provides an appreciable armor advantage.

**Samples S28-S30**

Samples 28-30 represented the summation of all cuir bouilli preparation methods. These samples were immersed in water at all three temperature ranges for the medial length of time, 60 seconds. Following this, they were baked, like S10-S18, and then waxed like S19-S27. Sufficient time was given between each preparation process to ensure that the previous treatment had been fully completed. The decision to only treat three samples in this manner was made for practical reasons regarding project resources, along with the observation that, at least superficially, the time immersed in the water made lesser difference than the temperature itself. Given the various hardening possibilities offered by each step of the preparation process, it should be clear that these samples were the most drastically different from the original vegetable tanned leather. S30 perhaps stands out as the most visible
declaration of this. Shrunken to 54% its original size, dried out by baking, and coated in beeswax, the immediate size disparity, sheen, and stiffness of this sample indicates the transformation it has undergone.

**Differential Shrinkage**

Shrinkage was expected with treatments that surpassed the threshold of 75-85°C. This contraction of the leather, quite dramatic in some cases, was due to the breakdown of hydrogen bonds that keep each collagen fibril taught in its natural state. The contraction is permanent, resulting in irreversible alteration of the fiber network.

Table 5.2: ‘A’ Group sample measurements after all *cuir bouilli* treatments.

<table>
<thead>
<tr>
<th>SAMPLE NUMBER</th>
<th>IDENTIFIER</th>
<th>DIMENSIONS (CM)</th>
<th>SURFACE AREA (CM²)</th>
<th>PERCENT SHRINKAGE (%)</th>
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</thead>
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<td>S1a</td>
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</tr>
<tr>
<td>S29a</td>
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<td>28.5 * 27.3</td>
<td>778.05</td>
<td>4.18</td>
</tr>
<tr>
<td>S30a</td>
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<td>20.6 * 21.2</td>
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<td>46.21</td>
</tr>
</tbody>
</table>
### Table 5.3: ‘B’ Group sample measurements after all cuir bouilli treatments.

<table>
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<tr>
<th>SAMPLE NUMBER</th>
<th>IDENTIFIER</th>
<th>DIMENSIONS (CM)</th>
<th>SURFACE AREA (CM²)</th>
<th>SAMPLE THICKNESS (mm)</th>
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</thead>
<tbody>
<tr>
<td>S1b</td>
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<td>28.8 * 27.3</td>
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</tr>
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</tr>
<tr>
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</tr>
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</tr>
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</tr>
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</tr>
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<td>S23b</td>
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</tr>
<tr>
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</tr>
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<td>3.15</td>
</tr>
<tr>
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<td>524.16</td>
<td>3.34</td>
</tr>
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</tr>
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<td>3.17</td>
</tr>
<tr>
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<td>21.5 * 21.4</td>
<td>460.1</td>
<td>3.35</td>
</tr>
<tr>
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<td>29.2 * 27.8</td>
<td>811.76</td>
<td>3.15</td>
</tr>
</tbody>
</table>

Samples that were initially boiled (any sample with an identifier beginning with 100), exhibited the most shrinkage as a group. These samples in some cases shrunk down to only 45% of their original size (S18a and S17b). Marks were kept on the stopwatch to note when this reaction would occur. In all cases, the leather darkened considerably in color around the 5 second mark, followed by a rapid deforming of the leather at 10-15 seconds as the shrinkage threshold was reached. All samples continued to shrink visibly for another 5-10 seconds, or until a final deformed state was reached, almost always rolled tightly in the shape of a roll [Figure
5.13]. In most cases, samples boiled for 60 or 90 seconds exhibited significantly
greater shrinkage than those boiled for only 30 seconds. Shrinkage appears to be a
trigger, occurring initially after 10 seconds of exposure. Depending how long the
leather is exposed to shrinkage conditions, the magnitude of this effect can be
adjusted.

While most samples shrank and contracted in a uniform pattern, maintaining
the roughly square shape they began as, others deviated from this pattern. When the
collagen bonds in leather fibers suddenly broke down, generally after 10-15 seconds
of immersion in boiling water, the leather curled upon itself from two distal edges. In
most cases, the leather rolled itself up in a tight spool, flesh side out. The direction of
this curl was determined by the overall direction of the grain, which when contracted,
pulled the leather inward on itself. Due to the tighter top grain, more densely packed
than the lower corium fiber layers, greater tension was experienced on this face of the
leather, determining the flesh-out pattern of the roll. These could be unrolled and
pinned down on the drying table without altering the shape of the leather. No
excessive tension was placed on any of the four sides of the leather, and the
contraction observed here could be measured and recorded accurately and without
complication.

However, in some cases, the leather contracted into a less uniform shape,
shrinking more in one region than another and producing more organic final shapes.
This might have been due to grain patterns that were multidirectional or intersecting.
Rather than rolling tight like a scroll, some samples would start curling inward from
three sides simultaneously. With three sides attempting to define the curl, the fibers
were not aligned and pulled the leather different directions. The remaining side was therefore left deformed by this tension and irregular shapes were produced [Figure 5.61]. While these conditions were not ideal, they did not imply failure either. These samples simply required greater care when unrolling, to preserve the naturally contracted shape without stretching, and greater attention when drying to ensure that an overall flat shape was defined. Calculating their surface area was simply a matter of breaking the shape down into smaller triangles.

Moreover, the disparate shrinkage observed in these samples points to the range of hardening effects that might be obtained [Figure 5.74]. While samples boiled for the maximum duration of time are compact and unyielding, those boiled for shorter durations are hard but flexible. It required greater testing to determine whether these samples’ armor performance was equally varied.

**Drying Concerns**

Drying all samples thoroughly while retaining a flat shape was without a doubt the most labor intensive part of the sample preparation. Despite what would appear to be an idle process, the leather needs frequent attention. Flipping the samples every couple hours increases air exposure and promotes even drying. However, while still wet, contracted leather fibers put tension on the leather and impose their own form that cannot be neglected. As I discovered early in the process, even those which had apparently accepted a flat shape would still warp if unbounded before completely dry. All samples needed to be clamped or fastened at their edges to prevent this curling that would compromise their testing integrity.
This is especially pertinent to boiled samples that experienced the most dramatic contraction and often times required additional weight to maintain a reasonably flat surface. Moreover, the difficulties experienced trying to control the shape of boiled samples conveyed the practical limitations of the material. If such laborious drying procedures were necessary to maintain the shape of plate armor sections on their lasts, it either signals the skill of their artisans or that modified procedures must have been used. This occurred to a lesser extent with baked samples, which take on an established shape more readily.

Waxed samples were the easiest to dry of all those produced. Since these samples were not resaturated in water, they did not need to endure slow evaporation before adopting a final shape. Rather, they only needed to cool to 64ºC, the melting threshold of beeswax. Immediately after being withdrawn from the wax pot, this cooling began to set in, offering rigidity and stability with far less toil. Thus, a shape could be defined immediately after removal from the wax and reached a stable state within minutes or hours rather than days.
Chapter 5 Figures:

Figure 5.1: S0a, 0.0.0.0, an untreated piece of Wickett & Craig’s vegetable tanned leather.

Figure 5.2: The vessel used for 15°C immersions and presoaking treatments, filled with cool water.
Figure 5.3: A sample soaking in 15°C water during initial water immersion treatments.

Figure 5.4: Measuring the temperature of the large pot used to prepare 55°C and 100°C samples.
Figure 5.5: Preparing a sample in 100ºC water, just starting to curl at its edges around the 10 second mark.

Figure 5.6: Boiled samples curled dramatically during after immersion in 100ºC water. This is caused by the contraction of collagen fibers, putting tension on the leather and deforming it. These samples required the greatest care to unroll, dry, and measure without altering the natural shrinkage.
Figure 5.7: Samples drying with wooden boards and additional weight used to pin down edges.

Figure 5.8: More samples drying after wax treatments.
Figure 5.9: Preparing the oven with foil over rack and a thermometer to verify temperature.

Figure 5.10: Baking previously boiled samples, using a second oven rack to pin down the leather and discourage excess curling.
Figure 5.11: Double boiler used to safely melt beeswax.

Figure 5.12: Melted beeswax in the double boiler basin.
Figure 5.13: Saturating a sample with beeswax. Note the darkened areas around the edges, moving towards the middle, indicating that the fiber network has been fully saturated. Lighter areas in the middle still retain air pockets in the fiber network.
‘A’ Group Samples

Figure 5.14 (left): S1a, 15.30.0.0

Figure 5.15 (right): S2a, 15.60.0.0

Figure 5.16 (left): S3a, 15.90.0.0

Figure 5.17 (right): S4a, 55.30.0.0
Figure 5.18 (left): S5a, 55.60.0.0

Figure 5.19 (right): S6a, 55.90.0.0

Figure 5.20 (left): S7a, 100.30.0.0

Figure 5.21 (right): S8a, 100.60.0.0
Figure 5.22 (left): S9a, 100.90.0.0

Figure 5.23 (right): S10a, 15.30.1.0

Figure 5.24 (left): S11a, 15.60.1.0

Figure 5.25 (right): S12a, 15.90.1.0
Figure 5.26 (left): S13a, 55.30.1.0

Figure 5.27 (right): S14a, 55.60.1.0

Figure 5.28 (left): S15a, 55.90.1.0

Figure 5.29 (right): S16a, 100.30.1.0
Figure 5.30 (left): S17a, 100.60.1.0

Figure 5.31 (right): S18a, 100.90.1.0

Figure 5.32 (left): S19a, 15.30.0.1

Figure 5.33 (right): S20a, 15.60.0.1
Figure 5.34 (left): S21a, 15.90.0.1

Figure 5.35 (right): S22a, 55.30.0.1

Figure 5.36 (left): S23a, 55.60.0.1

Figure 5.37 (right): S24a, 55.90.0.1
Figure 5.38 (left): S25a, 100.30.0.1

Figure 5.39 (right): S26a, 100.60.0.1

Figure 5.40 (left): S27a, 100.90.0.1

Figure 5.41 (right): S28a, 15.60.1.1
Figure 5.42 (left): S29a, 55.60.1.1
Figure 5.43 (right): S30a, 100.60.1.1

‘B’ Group Samples

Figure 5.44 (left): S1b, 15.30.0.0
Figure 5.45 (right): S2b, 15.60.0.0
Figure 5.46 (left): S3b, 15.90.0.0

Figure 5.47 (right): S4b, 55.30.0.0

Figure 5.48 (left): S5b, 55.60.0.0

Figure 5.49 (right): S6b, 55.90.0.0
Figure 5.50 (left): S7b, 100.30.0.0

Figure 5.51 (right): S8b, 100.60.0.0

Figure 5.52 (left): S9b, 100.90.0.0

Figure 5.53 (right): S10b, 15.30.1.0
Figure 5.54 (left): S11b, 15.60.1.0
Figure 5.55 (right): S12b, 15.90.1.0
Figure 5.56 (left): S13b, 55.30.1.0
Figure 5.57 (right): S14b, 55.60.1.0
Figure 5.58 (left): S15b, 55.90.1.0
Figure 5.59 (right): S16b, 100.30.1.0
Figure 5.60 (left): S17b, 100.60.1.0
Figure 5.61 (right): S18b, 100.90.1.0
Figure 5.62 (left): S19b, 15.30.0.1

Figure 5.63 (right): S20b, 15.60.0.1

Figure 5.64 (left): S21b, 15.90.0.1

Figure 5.65 (right): S22b, 55.30.0.1
Figure 5.66 (left): S23b, 55.60.0.1
Figure 5.67 (right): S24b, 55.90.0.1

Figure 5.68 (left): S25b, 100.30.0.1
Figure 5.69 (right): S26b, 100.60.0.1
Figure 5.70 (left): S27b, 100.90.01
Figure 5.71 (right): S28b, 15.60.1.1
Figure 5.72 (left): S29b, 55.60.1.1
Figure 5.73 (right): S30b, 100.60.1.1
Figure 5.74: Samples S1a-S30a stacked in numerical order. In this shot, the dramatic physical differences between certain sample groups is apparent.
Chapter 6: Testing Cuir Bouilli Samples

Unlike previous investigations into the manufacture of *cuir bouilli*, my project also included a performance study, seeking to measure the effectiveness of *cuir bouilli* plate armor. While others have made cursory attempts at expressing the differences between theorized methods, these qualitative judgments ultimately fall short. In order to fully realize the potential of *cuir bouilli* and understand its place within the canon of medieval armor, a series of trials needed to be undertaken. Such trials aimed to simulate the abuse armor would have been subjected to during actual use. Thus, I designed a series of three armor specific tests that quantitatively measured the performance of each sample I produced. Using the data obtained from these tests, it was possible to determine which individual samples, and thus which treatment methods, were most effective at eliciting desirable armor properties from the vegetable tanned cowhide.

Given the distinct and contrasting properties needed to achieve success in each of the three tests, disparities were observed between winning samples in each category. While one sample might have demonstrated high performance in the arrow test, for example, it may have struggled to achieve this level of performance in the impact test. There were not only category top performers -- the aggregate performance from these tests revealed which samples had the highest overall performance. It was my hope that among the 30 samples I produced, one if not more would reveal itself as an outstanding example, balancing desirable properties of elasticity, hardness, and resilience to achieve success in all trials. This sample would be considered of the most effectual method for crafting cuir bouilli armor, boasting
not only historically accurate methods, but verifiable performance. As such, it offers a practical understanding of the limits and pressures that might reasonably be sustained by *cuir bouilli* armor.

**Arrow Piercing Test**

The first test conducted was arrow piercing, intended to measure the ability of each *cuir bouilli* sample to slow or stop a shot arrow, minimizing penetration. Given the widespread use of longbows and other ranged weaponry during the chosen period, resistance to this type of attack would have been of considerable advantage and a primary concern of any armorer. Using samples S1a-S30a, the penetration depth of arrows shot under controlled circumstances was measured to determine the relative performance of each sample. This test was performed on January 14, 2014 at the All-Star Archery range in Lewisville, Texas. All arrows were shot from the maximum range at this facility, 20 meters.

The bow used to conduct this test was my own compound-type bow: a Mission Venture, 29inch draw length, 50 pound draw weight [Figures 6.1 and 6.2]. Like all modern compound bows, the Venture uses a system of cams and pulleys in its action to propel arrows with deadly force and accuracy. With arrows weighing 350 grains and an arrow velocity of 78 meters/second (256 feet/second), each arrow was calculated to strike the target with 66.5 newton meters (49 foot pounds) of kinetic energy.

While the strength of my own bow can be easily calculated, assigning a value to the kinetic energy typically generated by a longbow is more tricky. English
longbows of the period were typically a full two meters in length and cut from elm or Spanish yew. These bows shot an arrow longer than nearly any comparison, called a cloth yard arrow, 36 inches in length. At full draw, one of these bows could generate string tension of up to 180 pounds, effective at a maximum range of 400 yards in ideal conditions (Hall 1997: 19). However, the draw weight of any particular longbow used by medieval archers varies widely, with claims ranging from 80 pounds to nearly 200. Furthermore, the specific arrows used were even more varied in typology. These differences in length, weight, and other factors would undoubtedly have led to varying arrow ballistics, even amongst archers from the same region and period. Using surviving examples of English longbows as models, modern reproductions have been made (experimental archaeology projects in their own right), allowing us to approximate the energy they would have commanded (Kooi 1992). One such reproduction bow with a 110 pound draw weight finds approximately 53.915 foot-pounds of energy to be a reasonable estimate for this value. Nevertheless, this represents only one idiosyncratic example and does not define the strength of all longbows.

It is imperative to emphasize the importance of relative performance in this test, as well as those that follow. As you may point out, my compound bow is not equal in arrow velocity, nor foot-pounds of energy delivered to a historically accurate longbow. Furthermore, the basic mechanical principles that define each bow are distinct. My compound bow uses a pulley system to give the archer a mechanical advantage. Its frame is made of rigid fiberglass and it fires carbon arrows of modern manufacture, lighter and stronger than the timber shafts of historical arrows.
Longbows rely upon the naturally occurring elasticity of wood to generate power, which when bent puts enormous tension on the string. The precise energy an individual bow was able to produce is thus a function of unique properties in the wood and the geometry the bow stave. To further complicate standardization of the English longbow, the distance a bow is drawn will affect the ultimate velocity and kinetic energy of the arrow. Subtle differences in draw length, even if only a centimeter, will alter the tension exerted on the string by the bow limbs, resulting in varied arrow velocity. Thus, it is difficult to maintain a perfectly consistent shot.

Modern compound bows use a fixed draw length to defeat this problem. Once the bow has been drawn to the designed length, the pulley system will not turn further and a standardized release can be made. This allows greater consistency between shots, ensuring that all arrows are released at maximum draw and string tension. Obviously, given the radical differences between these bows, the specific performance of cuir bouilli samples will be distinct. The depth an arrow penetrated a sample using my compound bow, would not necessarily have matched that of the longbow. Rather, the relative performance of each sample revealed essential trends in the material’s strengths and weaknesses. The order of highest to lowest performing samples should retain the same relationships, despite the differences between historical and modern archery equipment. In this way, the bow was generalized and allowed to function as a scientific instrument.

The test was designed to allow me to measure the depth an arrow could penetrate into each cuir bouilli sample with a foam archery backstop behind it. Due to the immense energy arrows shot from compound bows are able to achieve, a backstop
was necessary to prevent blow-throughs, where the entire arrow passed through the sample, leaving it unable to be measured. By placing the backstop close behind each sample, the performance of each leather sample could be measured, as compared to the control depth of penetration [Figure 6.3]. The foam backstop provided a predictable material for the arrows to terminate in. It uses uniform layers of foam padding to slow the arrow to a stop, exerting the same absorption properties regardless of the point of impact. Thus, the leather was able to knock down as much of the arrow velocity as initially possible. Once the arrow pierced the sample, it was slowed to a final stop by the backstop, which acted as a constant and held the arrow at its final penetration depth. Once all three arrows had been fired into each cuir bouilli sample, the shafts were taped to mark the maximum depth [Figure 6.4]. Arrows were then removed from the sample and measured. This average depth was used to infer the performance of a given sample against arrow piercing.

Samples were prepared for the testing by drilling a small hole in each corner. A wood bit was found to be effective at boring through the leather without damaging the surrounding area, especially with the more brittle samples. These holes were used to pin each sample to the foam backstop. Some space was left between the sample and backstop, allowing the leather to take effect momentarily and slow the arrow before the backstop stopped the arrow. Nylon spacers were used to standardize a 1.5inch gap between the leather sample and the backstop [Figure 6.5]. All samples were marked with a prominent ‘X’ to designate the center of the target and assist in aiming. However, the exact center of each sample was not necessarily the desired point of arrow impact. The three arrows were aimed to strike three distal regions of
each sample, the group roughly resembling an equilateral triangle, to promote a more thorough exploration of each sample [Figure 6.3]. This shot placement allowed me to measure whether samples exhibited consistent strength across their entire surface. It also minimized the possibility of earlier arrow damage affecting subsequent shots if too close together.

As mentioned earlier, the performance of each sample was understood as the difference in arrow penetration from the control data collected prior to testing. This control was measured by substituting a plain sheet of printer paper for a leather *cuir bouilli* sample. The sheet of paper, offering little to no resistance on the arrow, was attached to the backstop like all tested samples. Arrows shot at the control were minimally affected by paper and slowed to a stop by the backstop alone. With the sheet of paper suspended in front of the target, on the same plane a leather samples were measured from, a controlled value for arrow penetration could be collected -- 36.7cm. Any deviation from this measure could therefore be attributed to the ability of each *cuir bouilli* sample to resist arrow piercing. All arrow piercing data may be found in the following [Table 6.1].
Table 6.1: Raw arrow penetration data

<table>
<thead>
<tr>
<th>SAMPLE NUMBER</th>
<th>IDENTIFIER</th>
<th>ARROW PENETRATION (CM)</th>
<th>AVERAGE PENETRATION (CM)</th>
<th>GROUP AVERAGE (CM)</th>
</tr>
</thead>
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<tr>
<td>S1a</td>
<td>15.30.0.0</td>
<td>23.3, 22.8, 23.0</td>
<td>23.033</td>
<td>23.733</td>
</tr>
<tr>
<td>S2a</td>
<td>15.60.0.0</td>
<td>25.3, 25.0, 20.6</td>
<td>23.633</td>
<td></td>
</tr>
<tr>
<td>S3a</td>
<td>15.90.0.0</td>
<td>25.1, 24.0, 24.5</td>
<td>24.533</td>
<td></td>
</tr>
<tr>
<td>S4a</td>
<td>55.30.0.0</td>
<td>24.0, 25.9, 22.4</td>
<td>24.100</td>
<td>24.066666667</td>
</tr>
<tr>
<td>S5a</td>
<td>55.60.0.0</td>
<td>25.1, 29.0, 21.9</td>
<td>25.333</td>
<td></td>
</tr>
<tr>
<td>S6a</td>
<td>55.90.0.0</td>
<td>22.0, 22.8, 23.5</td>
<td>22.767</td>
<td></td>
</tr>
<tr>
<td>S7a</td>
<td>100.30.0.0</td>
<td>28.6, 28.9, 31.1</td>
<td>29.533</td>
<td>30.344333333</td>
</tr>
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Impact (Blunt Trauma) Test

This test was intended to measure the ability of each sample to resist impact delivered by a wooden sledgehammer. It simulated an attack with a non-edged striking weapon, such as a club or hammer. To effectively deflect a blow like this, armor must be able to distribute the blow over a larger surface area. In doing so, the focus of the attack is diminished and the trauma is dispersed over a larger area of the body, potentially making the difference between broken bones and deep bruises.

To conduct this test and collect data, I constructed a striking rig from lumber and used a Vernier force plate sensor to measure the impact delivered at a given moment [Figures 6.6 and 6.7]. Using an iron pipe as the axle of rotation, a 4x4 wooden beam was dropped from a known height, delivering a consistent impact each time. The length of the striking arm was approximately 1.63 meters and was modified to have a more pronounced striking face, constructed from a wooden block and piece of baseball bat [Figure 6.8]. The entire arm weighed 8.2 kilograms, and depending upon the height the arm was raised to before being dropped, the force of the impact could be scaled. At this fixed point of impact, a wooded wedge was used to prop the force plate up at an angle perpendicular to the direction of the hammer strike. This ensured a square impact, more easily identified by the sensor.

Each cuir bouilli sample sat atop the force plate with folded layers of a padded blanket in between. This quilted blanket was meant for industrial moving purposes, used to protect large objects against bumps and scratches. When layered, the blanket provided a cushion with adjustable thickness, serving as the medial layer between cuir bouilli samples and the instrument’s surface. It was meant to approximate the
role of an *aketon* or *gambeson*, padded jackets worn as a base layer with protective armor. While the primary purpose of this padding was to provide approximate historical conditions, it also provided a medium for the force to travel through.

Vernier’s Logger Pro software was used to collect data and generate graphic readouts of each impulse. For the purpose of this experiment, the force plate was set to collect 500 data points per second. While the final testing height prescribed lifting the arm only 55cm off the floor, there was a significant troubleshooting process which guided me to arrive at this specific height and force standard.

When preliminary impact tests were administered, inconclusive data signaled that modifications to the apparatus itself were necessary. In this exploratory attempt, the arm was dropped from a height of 1.52 meters (5ft), striking the force plate with 1704 Newtons (383 pounds) of force against the four layers of blanket padding. This particular height was chosen because it roughly replicated the amount of force behind a swing with a baseball bat. This strike served as a generalized impact standard, acting as a temporary baseline for comparing the effectiveness of each sample. Mechanical inefficiencies, however, prevented this design from collecting useful data. In this initial configuration, the wedge was not secured to either the ground or the hammer frame itself. It moved across the floor when struck, detracting from the sensor’s ability to accurately measure impact. Additionally, the force plate was not bolted to the wedge, allowing some bounce to occur and force to escape the sensor. It was quickly realized that all samples produced the same data, even samples that were radically different, both in treatment and physical characteristics. Identical data maps could not characterize such dissimilar samples. Moreover, the tested samples
exhibited impact spikes that were exactly like that of control. This data suggested that *cuir bouilli* samples were taking no effect on the dispersion of force throughout the sample, despite the obvious hardening which characterized them.

Subtle modifications to the rig and procedure were necessary in order to tease out the material differences between each sample. These modifications encouraged greater consistency in methods and more legible and accurate collection of data. The first modification was the excess *bounce* and flexibility that characterized the rig. Since the wedge was not initially secured properly, it provided an outlet for the energy of the impact to escape the force sensor. This was exacerbated by the bounce occurring between the force plate and wedge when struck. To remedy this, the force plate was bolted to the wedge, fixing it in place. The entire wedge structure was then bolted to the hammer frame. Thus, the entire system was made more rigid, able to directly transmit energy from the hammer arm, through the *cuir bouilli* sample, and into the force sensor. Additional layers of quilted padding were also added, enhancing the medium for the impulse to travel through and better approximating the density of armor on the body. Finally, the striking face of the hammer was modified to make use of a fitted length of baseball bat. This provided a more focused, but elongated strike face and exposed a wider area of the sample to the blow. Not only did this better simulate the effect of an actual bludgeon, it also gave each *cuir bouilli* sample greater opportunity to disperse the impact, rather than being overwhelmed in a concentrated area.

Perhaps the most important modification made to the testing procedure was finding the ideal height to drop the hammer arm from. In preliminary attempts, the
arm was dropped from a height of 1.52 meters (5ft). Initially this height was chosen because it roughly simulated the same effect as being struck by a baseball bat. However, continued parallel performance of *cuir bouilli* samples led me to believe that this was too much force. With such a tremendous impact, the baseball bat was able to press its way through any sample, dramatically deforming it momentarily and allowing nearly all of the impact energy to be detected by the force plate. The samples were unable to take any significant effect on dispersing the energy. It seems likely that such a high impact exceeded the capabilities of leather armor. Even the toughest *cuir bouilli* might not have been adequate protection from a full strength swing with a blunt weapon. The blow simply overwhelmed each sample.

However, a lighter impact was found to be effective at revealing the material differences between samples. By lowering the drop height to only 75cm, half the initial height, useful data immediately presented itself. Through a series of trial and error test drops, the ideal height to drop the hammer arm from was identified. This final height of 55cm garnered data with the most pronounced marginal differences between disparaging samples, emphasizing performance trends. Striking with a baseline control of 1080 Newtons (243 pounds) of force against 12 layers of quilted blanket, all 30 *cuir bouilli* samples were be compared to this control measure to reveal their ability to disperse impact.

Each sample was struck three times, using the force plate and Logger Pro software to log data points and graph the impulse. Careful attention was maintained to ensure all samples were aligned with the force plate, the blanket was layered
properly, and the hammer struck in a consistent location, ensuring uniform conditions for each drop. The results of this test are displayed in the table that follows.

**Table 6.2: Raw impact (blunt trauma) data.**

<table>
<thead>
<tr>
<th>SAMPLE NUMBER</th>
<th>IDENTIFIER</th>
<th>RECORDED IMPACT (N)</th>
<th>AVERAGE RECORDED IMPACT (N)</th>
<th>GROUP AVERAGE (N)</th>
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</table>

*Sample was cracked, shattered, or otherwise destroyed by impact.*

As with the arrow piercing test, this scenario was also generalized to an extent. It did not test the performance of any specific type of weapon. Rather than attempting to replicate a medieval battle scenario, the rig was meant to function more
like a scientific tool. The materials and forces used in my experiments were meant to promote the clearest trends in data and offer positive data confirmation of the perceivable differences between samples. To do so, the tests themselves were neutral. By this I mean that the rigs and test conditions did not perform in a way that would detract from the collection of data. A baseball bat is clearly not an outstanding example of medieval weaponry, but provided a predictable input upon each sample. It did not over assert itself, nor did it obscure the basic physical challenge in question. To this end, the varied performance observed between samples could be attributed to their material differences and preparation procedures, not to the rig.

**Slashing Test**

The third and final test I administered was a slashing test. This challenge was designed to measure the resistance of *cuir bouilli* samples to cutting or lacerations. Such damage could have been sustained from attacks with edged weapons including swords, axes, or even spears. In some ways, this test is a conflation of the arrow piercing and blunt trauma tests that preceded it. If an individual were struck with a sword, for example, the inflicted damage was due to both impact and penetration. Obviously, the edge seeks to slice through the defensive material, splitting it with a sharpened wedge similar to arrow piercing. However, even if the edge is deflected, significant trauma might still be sustained, capable of producing nasty impact wounds all the same.
Slashing has always been a defensive concern. Chain-mail was designed for this specific purpose and had been part of the costume of warriors for millennia.\(^{51}\) This test demonstrates how the addition of *cuir bouilli* defensive elements might have provided extra protection against slashing. Their measured success or failure expands the trajectory of armor development, giving reason for its abandonment in favor of metal plate or perhaps revealing applications where it might have remained relevant.

To administer the slashing test, the hammer rig used to conduct impact tests was retrofitted, altering the striking end to function as a cutting instrument. Rather than being fitted with a baseball bat striking face, a large hunting knife was affixed in its place. The knife was bolted directly to the end of the arm, letting the blade project in its entirety [Figure 6.10]. When dropped from a known height, the knife was ‘swung,’ taking a swift slash at whatever stood in its path [Figure 6.11].\(^{52}\) The knife chosen for this task was an Ontario RAK (Ranger Assault Knife). Designed for bushcraft or combat use, the RAK has a cutting edge length of 5 inches and an overall length of 12 inches. The neutral, spear point blade shape gives the knife a well pronounced *belly* with which to cut. This blade curvature maximizes the length of the cutting edge compared to the length of the blade itself.

Understanding this blade geometry was crucial to the design of the rig itself. Edged weapons can either function by slicing or hacking. The belly, curved to maximize the cutting edge, encourages material to slide across the length of the blade.

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51 There is evidence that chain-mail had been used as far back as the Romans. In the principal period I am investigating, Europe during the 11th to 14th centuries, mail was a commonplace defensive garment, along with padded gambesons. While these two pieces of armor were well established before *cuir bouilli* gained a foothold, its addition to the costume might have provided an additional margin of protection and was a necessary stepping stone on the path to fully realized plate armor.

52 Basically, it is a centrifugal guillotine.
Thus, the honed edge is drawn through material, slicing as it does so. Cutting like this would have most commonly been associated with weapons bearing curved edges, such as scimitars. In contrast, the straight section closest to the handle of the blade chops through material. It is percussive and uses the edge to hack rather than slice. Edged weapons such as axes or straight edged long swords would be expected to produce this kind of slashing damage. On the night prior to testing, the knife was sharpened and given an edge geometry of 30°. As knives go, this is a somewhat thick edge, but necessary to withstand the abuse the test would deliver. Nevertheless, once stropped to a polished finish, it could slice cleanly through paper with ease and was fearsome to the touch. As ensuing tests confirmed, the knife had no trouble cutting the leather, and, even after all slashes were made, retained its working edge. This can be attributed the 1095 high carbon steel the blade was forged from, balancing the essential properties of hardness and toughness to produce a long lasting slicing tool.

Due to the generalized shape of this blade, it is versatile and able to produce a wide range of slashing effects. It adequately summarizes the edge weapon attacks that would have characterized a medieval battlefield into a single motion. Yet ensuring that the blade could operate as desired was also a function of target positioning. Since the blade was fixed in place on the arm, its angle of attack could not be adjusted -- the rig dropped the blade in the same arc each time. To ensure that the blade struck each sample in a way which maximized its slashing potential, the sample itself needed to be situated at the correct distance and angle in relation to the cutting path.

A secondary rig was built to remedy this [Figure 6.12]. Functioning as a frame that samples could be attached to, the angle could be adjusted incrementally using a
series of holes drilled in the wood. 550 paracord was used to string up each sample through the predrilled holes in each corner. When threaded through different holes along the length of the frame, the angle could be tuned to an optimal position, then secured using rope cleats at each corner of the frame.53 Using previously spent samples (‘A’ group), a trial and error process was undertaken to determine the most effective sample positioning. Eventually this orientation was achieved with the sample angled at 50° in relation to the ground and 30cm separating the two frames. This orientation allowed the flat length of the blade to make the initial chop in the sample section, then transition to slicing through the remainder of the sample as the belly made contact. 1.5 meters was chosen as the drop height. This height was easily repeatable. Also, given the difficulties experienced during the impact test, the possibility of striking with too much force was feared. At any height significantly higher than 1.5 meters, the knife arm became difficult to aim, making consistency between strikes complicated.

As with all tests, ensuring uniform circumstances for each trial was a primary concern. Since variations in size existed between samples, it was necessary to standardize the height each piece of leather was suspended in the rig at. While the angle would remain constant, as dictated by the tie down points, variations in the length of the four securing ropes could allow the sample to sit higher or lower in the frame. If this were the case, the distance the blade fell before making contact might vary, producing flawed data. To ensure that the initial point of impact remained constant, each sample was tied up in the frame by the two top fastening points first.

53 Holes were spaced every 4cm on the vertical and horizontal beams of the frame. 550 paracord was chosen for this application due to its strength (minimum rating of 550 pounds), thin diameter (stays out of the cutting path), and general availability.
These lengths of paracord could be adjusted so that the top edge of the sample was consistent with a chosen reference point. Once secured at this height, the lower fastening points were strung to the horizontal beam and the line pulled tight.

When struck by the knife, the paracord acted as a simple suspension system as the lines stretched momentarily. This ‘give’ built into the rig accounted for two things. First, it better simulated actually being struck by a sword. Either the body which receives the blow will be pushed back, or the arm of the attacker will buckle to a degree -- in either case the system is not completely rigid. Second, the suspension lines kept the cuiir bouilli samples pressed tight against the blade as it passed by.

With all conditions of the experiment controlled, testing of cuiir bouilli samples S1b-S30b transpired. Three slashes were delivered to each sample, all from a drop height of 1.5 meters. Between each slash, the frame was offset slightly to the left or right to avoid cutting through an already existing gash. After all slashes were delivered, the damage each piece sustained was measured and assessed.

The severity and depth of cuts often varied even within a single slash. The edge of the sample, where initial contact with the blade occurred and chopping cuts were made tended to sustain deeper cuts. As the blade was drawn through the belly towards the middle of the sample, gashes tended to be shallower, mostly due to the rapid slowing of the blade after first impact. Thus, three points of measurement were used to judge performance: sample thickness, edge slash depth, and middle slash depth. Using calipers and a machinist’s ruler [Figure 6.13], the thickness of each sample and depth of any particular gash was measured. The greatest measured value for each data point was recorded as the final depth. These two slash depths could then
be averaged and expressed as a percentage of total thickness. In cases where the blade cut completely through the sample, the slash depth is recorded as the full thickness of that particular sample.

Table 6.3: Raw slashing data.

<table>
<thead>
<tr>
<th>SAMPLE NUMBER</th>
<th>IDENTIFIER</th>
<th>EDGE SLASH DEPTH (mm)</th>
<th>MIDDLE SLASH DEPTH (mm)</th>
<th>AVERAGE SLASH DEPTH (mm)</th>
<th>SAMPLE THICKNESS (mm)</th>
<th>SLASH DEPTH AS PERCENT (%)</th>
<th>GROUP AVERAGE (mm)</th>
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As the data above demonstrates, four of the tested *cuir bouilli* samples were cut cleanly in half by the knife [Figure 6.14]. Many more were cut all the way through only at the sample edge with the middle section resisting the slash. Perhaps...
most important to point out, however, is that seven samples could not be tested against slashing at all. These untested samples were all previously boiled at some point in their *cuir bouilli* treatments. Due to irreparable damage sustained during the impact and arrow piercing tests, these samples were highly irregular in shape and could not be strung up consistently in the frame.
Chapter 6 Figures:

Figure 6.1: *Mission Venture* compound bow used for to test samples against arrow resistance. Draw length 29”, 50 pounds.

Figure 6.2: Round nosed arrowheads used for testing. These arrowheads are meant for target use and are not aggressively in geometry. Their rounded striking point gives each *cuir bouilli* sample maximum potential to resist penetration.

Figure 6.3: *Cuir bouilli* sample in front of the foam backstop. Note the wide shot placement, intended to explore the maximum sample area possible.
Figure 6.4: Arrows taped at maximum penetration depth for measurement.

Figure 6.5: Nylon spacers used to space each sample 1.5 inches in front of the backstop.
Figure 6.6: The entire striking rig. The arm could be lifted to a standardized height to deliver a consistent impact at a fixed point.

Figure 6.7: The force plate was attached to a wooden wedge to ensure a direct strike.
Figure 6.8 (left): Baseball bat striking face, representing a generalized bludgeon.

Figure 6.9 (right): 12 layers of moving blanket between each *cuir bouilli* sample and the force plate, approximating the consistency of a gambeson.

Figure 6.10: Hammer rig retrofitted with a knife blade to function as a slashing rig.
Figure 6.11: The entire slashing rig setup.

Figure 6.12: Secondary frame rig built to hold each *cuir bouilli* sample during slashing tests. The angle could be adjusted using preset holes on the beams, then tied tight using 550 paracord.
Figure 6.13: Calipers and machinist’s ruler used to measure the slash depth at any point on each sample.

Figure 6.14: Spectacular failure of a baked sample which was cut clean in half by a single slash.
Chapter 7: Results and Analysis

The information these three tests yielded serves as my basis for all further claims regarding the effectiveness of *cuir bouilli* as plate armor. My method for judging the effectiveness of each sample is based upon a simple ranking system, using the performance of each sample in each test to construct a hierarchy. According to this ranking, each sample is awarded a score from 1-30, 30 being awarded to the top-performing sample in each of the three tests. After three tests, scores can be totaled and ranked. The highest composite score, with a potential maximum of 90 points is representative of the highest overall performer from the group of 30. In the case that two samples score the same, further consideration may be needed to determine whether one has a performance edge over another -- though this is not necessarily the case. Other indications of performance, some qualitative, can be inferred from the damage a sample sustains and used to further discern effectiveness in a given application. These traits might require closer visual analysis of the sample, looking for subtle deformations or damages in the fiber structure which may not be manifested in the data. The highest achieving samples display above average performance in all three tests, effectively balancing properties such as rigidity, elasticity, and toughness to defeat the abuse they are dealt.

Again, it must be reiterated that the conclusions drawn from these tests cannot be taken as direct indications the performance of historical armor. Forces and implements used to attack the samples are generalized. They are intended to reveal the essential physical trends *cuir bouilli* hardening treatments might have on leather,
and how they affect performance as armor. This does not confirm on guarantee that it was used in such a way -- only that it is viable at a material level.

**Arrow Piercing Data and Analysis**

Table 7.1: Ranked arrow penetration data with scores assigned.

<table>
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<th>SAMPLE NUMBER</th>
<th>IDENTIFIER</th>
<th>Temperature Map</th>
<th>Time Map</th>
<th>Bake Map</th>
<th>Wax Map</th>
<th>AVERAGE PENETRATION (CM)</th>
<th>ARROW SCORE</th>
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The highest and lowest performing samples, S6 and S27, respectively, are highlighted in green and red. In addition, two controls were tested, an untreated piece of leather and a sheet of paper. The sheet of paper offers no resistance to the arrow, establishing 36.767 cm as the baseline of arrow penetration. Any decrease in penetration depth may therefore be attributed to the samples resistance. Samples that were only treated using sub-shrinkage water immersion temperatures performed more effectively, than those that had been baked or waxed. In order to further elucidate this trend, the effect of each variable will be examined individually, comparing their performance to preceding samples to isolate the effect of each.

**Water Immersion/Boiling**

Two variables were most crucial to the cuir bouilli water immersion preparation process: temperature of the water, and duration of time immersed. All 30 unique samples underwent an initial water immersion step where they were exposed to one of three temperatures (15°C, 55°C, or 100°C) for either 30, 60, or 90 seconds. While temperature governs the potential for shrinkage, the duration of time exposed to this temperature determines its magnitude. Since both variables are intrinsic to the process, each temperature must be considered in relation to the duration it is paired with. Samples S1a-S9a, unobscured by compounding treatments, provide the clearest platform for assessing these effects.

As the ranked table demonstrates, samples that have been immersed at either 15°C or 55°C appear in an erratic order, with the majority falling within the upper performing half. Of the top ten performing samples, four were prepared using 15°C water and five prepared using 55°C water. While this might technically suggest that
55°C samples are advantageous, the continued fluctuation of either temperature in the remaining ranks obscures any further trends concerning only these two temperatures. It can be said with certainty though that lower temperature immersions produced leather that was far more effective at reducing arrow penetration than boiled (100°C) leather.

Among samples prepared at 15°C, the length of time immersed in the water does not seem to have had a profound effect on performance against arrow penetration. S1a-S3a exhibited a range of only 1.5cm difference in arrow penetration. Given the mild temperature, it is unsurprising that these samples were not drastically affected by the duration of time immersed. 15°C is significantly lower than shrinkage temperature and there is little effect to be had.

Samples with prolonged exposures to 55°C water also experienced some appreciable penetration resistance. The highest performing sample, S6A, belonged to this temperature range, with an average penetration depth 14cm less than the paper control and 1.5cm less than the untreated leather control (0.0.0.0). This might suggest that the oil stripped from leather by warm water occurred more thoroughly with increased time, decreasing the suppleness of the leather and increasing its apparent toughness.

It should be noted that because 15°C samples are exposed only to cool water, they are the closest parallels to untreated vegetable tanned leather. This is confirmed by the similar performance of S1a-S3a to the second control, an untreated piece of vegetable tanned cowhide (0.0.0.0). Furthermore, samples that were immersed in 55°C water exhibit arrow penetration nearly identical to this control. Thus, there
appears to be little functional difference between samples that have exposed to water cooler than shrinkage temperature. Nevertheless, the properties of unhardened vegetable tanned leather are most effective at resisting arrow attacks. Its pliability and elasticity allowed the leather to tightly grip the shaft of an arrow it, slowing it more rapidly and decreasing its traveled depth [Figures 7.1 and 7.2].

The overwhelming saturation of boiled samples in the lower performing half of the sample group is indicative of the ill effect boiling had on resistance to arrow piercing. Of the ten samples that were boiled initially, seven occupy the lowest performing positions in this particular test. Despite their apparent hardness when handled, this did not translate into a useful armor property. Most samples shattered upon arrow contact [Figure 7.3], or in slightly less severe cases, were destroyed only in the area immediately surrounding the arrow [Figure 7.4] Rather than gripping the arrow, slowing its velocity and minimizing penetration, the arrow is able to pass through the sample with no resistance following initial contact.

The ten samples prepared using boiling water were expected to have the most profound differences between varying time prescriptions. Boiling water quickly penetrates the hide and has rapid effects on leather. The longer a sample is exposed to these beyond shrinkage threshold temperatures, the more dramatic the hardening and increase in density. As a result, samples prepared using extended immersions in boiling water allowed the greatest arrow penetration. The three samples that were boiling for the full 90 seconds (S9a, S18a, S27a) placed in the bottom four of the entire group. While it seems that prolonged boiling decreased the effectiveness of boiled samples, briefer exposures garnered slightly more favorable results. Samples
that were boiled for only 30 or 60 seconds outperformed those boiled for 90 seconds in all but one instance (S25a). Thus it appears that marginal success might be achieved with a limited or more controlled exposure, but the full-length boil renders samples overly brittle and generally ineffective in this application.

**Baking**

To my surprise, baking was also found to be nonproductive, allowing greater depth of arrow penetration than comparable non-baked samples. This is perhaps most apparent when comparing S1a-S9a to S10a-S18a. In these two groups, each baked sample can be paired with a non-baked sample that was otherwise prepared using the same methods. Despite the minor hardening baked samples achieved, apparent at least to the touch, this alteration did not translate into a desirable armor property. Baked samples allow a full 5cm greater arrow penetration in some cases (S3a & S12a). Within this group, there is not a single baked sample that outperformed its associated non-baked sample, thus leading me to conclude that this specific treatment was overall ineffective at providing protection from arrows.

However, one sample that had been baked finished in the top 5-performing arrow piercing samples. This particular sample, S15a (55.90.1.0), is in some ways an outlier, demonstrating a disproportionately high performance compared to baked samples that immediately precede and follow it. However, the performance of S6a, its unbaked comparison, reveals that this particular water immersion treatment was also characterized by high arrow piercing resistance, securing the top rank of all 30 samples. Thus, the outlying high performance of S15a might be attributed to immersion methods rather than baking. The detrimental effect baking had on each
sample is reinforced in samples that had been both boiled and baked. When baking is compounded upon this already poor performing platform, resistance to arrow penetration suffers again. These samples (S16a-S18a) represent the worst performing group in this test, confirming the ill effect of both treatments.

**Beeswax**

Despite the apparent durability and robustness offered by wax treatments, they also had negative effects on the samples’ resistance to arrow piercing (S19a-S27a). Again, comparison to unwaxed samples (S1a-S9a) reveals that waxing leather will result in greater arrow penetration. With an average difference of 4cm greater penetration depth, across the board wax stuffed samples performed worse than their unwaxed counterparts.

While brittleness can be identified as the weakness of boiled or baked samples, waxed samples exhibit no signs of this defect. Rather, they are quite pliable and resistant to cracking. The wax imparts enough rigidity to harden the sample while still allowing itself to deform. Their poor performance, I believe, is due to the beeswax acting as a lubricant for the arrow. With unwaxed samples like S6a or the control, a tight seal is formed around the shaft of the arrow at impact. This squeezes the dry leather fibers against the arrow, slowing its velocity and decreasing the depth the arrow is able to penetrate the backstop thereafter. With waxed samples, this seal is formed but does not grip sufficiently. In the brief instant that the arrow strikes the waxed sample, the wax in the immediate area touching the arrow melts due to the friction induced heat. This lowers the friction coefficient, perpetuating the arrow more than an unwaxed sample would.
Despite its inefficacy as arrow protection, waxed leather is considerably more durable than boiled leather. While arrows cracked or shattered all boiled samples, they had no such effect on waxed *cuir bouilli* [Figure 7.5]. The arrow could be removed and the plate remained structurally undamaged otherwise.

**Impact Data and Analysis**

Again, the highest and lowest performing samples are highlighted in green and red [Table 7.2]. S9b (100.90.0.0) was the top performer, allowing only 571N through to the force plate. S1b (15.90.0.0) was the lowest performing sample, permitting 1022N. A *gambeson* substitute, provided by a quilted moving blanket, served as a control. Any deviation from this baseline of 1080N (roughly 250 pounds) of force measured can be attributed to the protective value of each sample. Analysis of the impulse spikes associated with each sample also demonstrates the functional differences between samples [Figure 7.6].
Table 7.2: Ranked impact data with scores assigned.

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<th>Time Map</th>
<th>Bake Map</th>
<th>Wax Map</th>
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* Sample was cracked, shattered, or otherwise destroyed by impact.

Water Immersion/Boiling

Samples that were prepared using only a 15ºC water immersion (comparable to untreated vegetable tanned leather), exhibited the poorest performance at impact protection. As S1b (15.30.0.0) demonstrated, only 60N of force was dissipated by this
sample, scarcely better than the *gambeson* control. Prolonged exposure to cold water seemed to be marginally more effective, reducing the detected impact by about 120N. Nevertheless, all three samples (S1b-S3a) placed within the 6 lowest rankings. This leather exhibited no rigidity, retaining its suppleness and pliability. Despite its advantages in arrow protection, such soft armor is unable to provide appreciable protection from blunt trauma attacks. The leather bends and deforms, allowing the bludgeon to press through the material and deliver an impulse of force to the body which is largely unaffected by these protective measures [Figure 7.7].

Likewise, samples that were prepared using only a 55°C water immersion process exhibit minimal impact protection. S4a-S6a as a group were the poorest performing in this challenge, resisting only 100N (~20 pounds) of force. Their performance was not affected by the duration of time immersed, at least within the 90 seconds explored here. Despite the loss of lubricating oils, giving them some tactile rigidity, the blow overpowers these samples. They bend and deform akin to 15°C samples or untreated leather, providing only cursory armor benefits.

Exceptional performance was exhibited by samples that were prepared using boiling water. As S7a (100.30.0.0) demonstrated, even a brief exposure to 100°C water produced substantial impact resistance, deflecting 220N of force. This potential was magnified with longer exposures. S8a, boiled for 60 seconds, deflected an additional 80N of force while S9a, boiled for 90 seconds, blocked a staggering 500N of impact from reaching the plate. S9a was the top performer in this specific trial, reducing the detected impact to nearly half of its baseline value [Figure 7.8]. Of 10
samples that had been boiled, all placed within the top 20 ranks in this trial -- 7 within the top half. Moreover, of the top 6 performing samples, 5 were boiled.

Thus, the trends observed in impact protection are the reverse of those observed in arrow piercing. Unlike arrow piercing where elasticity is required to grip the arrow, impact resistance is a function of rigidity. Rigid samples are able to disperse the impulse of force across their surface. As the energy travels outward, spreading over a larger area, the impact becomes less focused. Thus, the plate dissipates much of the energy that would otherwise be directed into the body. However, it should also be recognized that this is not without cost. Many of the boiled samples (7 of 10) cracked or shattered upon impact, compromising their continuing structural integrity. Nevertheless, these samples were among the top performers. It appears that this ability to shatter might be advantageous for impact protection, the product of a dramatic and sudden dispersion of energy.

**Baking**

Baking produced an appreciable armor advantage in samples with an initial 15° or 55°C water immersion treatment. Comparison of S10b-S15b to their unbaked analogs S1b-S6b revealed considerably more deflected impact in the baked condition, providing up to 140N of marginal impact protection [Figure 7.9]. The rigidity of baked samples can be attributed to their slight shrinkage and compaction of leather fibers. These alterations allow the leather to absorb and redirect impact forces across its surface more efficiently.

The advantages of baking are not universal among previously boiled samples. S16b (100.30.1.0) experienced a dramatic jump in resistance to impact attacks,
deflecting 150N more than its unbaked parallel. However, baked samples S17b and S18b, previously boiled for 60 and 90 seconds respectively, are significantly less effective at deflecting impact. S18b allowed 879N to reach the force plate, 300N more than S9b. Thus, it seems samples that have already experienced prolonged boils are hindered by additional shrinkage treatments. Compounded baking overuses the shrinkage mechanism, resulting in samples that are too brittle and cannot adequately disperse the impact energy across their surface. Though as S16b indicates, samples boiled for a shorter duration stand to gain impact protection from additional baking. In these cases, the leather has not yet been hardened fully, nor has the structure turned excessively brittle, allowing the ambient temperatures to enhance hardening effects. Moreover, this sample did not shatter upon impact, indicating that it retains some elastic properties that enhance its durability.

**Beeswax**

Beeswax stuffing also provided a considerable armor advantage against blunt trauma attacks. Comparison of waxed samples S19b-S27b to S1b-S9b reveals the heightened performance of waxed samples in all but one instance (S27b). On average, they were able to disperse 170N more than unwaxed samples, signifying a substantial armor enhancement [Figure 7.10]. Moreover, all waxed samples exhibit impact protection that eclipses that offered by baking. In some cases, waxed samples were able to deflect 100N more than baked counterparts (S21b, S22b).

The success of beeswax treatments is due to pliability rigidity. When a sample is fully saturated with beeswax, the wax occupies minute pockets in the fiber network that would otherwise contain air. Once cooled, the wax solidifies, compounding its
structure with that of the leather. The sample grows slightly in thickness due to the addition of new material. Beeswax bestows instantly appreciable rigidity to vegetable tanned leather, but its real mechanical advantage in impact applications is its ability to deform without shattering. After a momentary deformation, waxed samples almost immediately spring back to their original, flat form with no apparent damage. Unlike boiled samples, they did not sustain permanent damage.

Samples that have already been boiled are less receptive to the benefits offered by beeswax treatments. This is likely due to their already compact fiber structure, obstructing saturation with wax. Rather, wax sits on the surface of these samples, unable to provide internal structure to the collagen network. Samples that were both boiled and waxed performed the best as a group, despite S27b’s deviation from the larger trend. However, it should be considered that the initial boiling was more instrumental in this performance. All such samples were destroyed upon impact, demonstrating an acute debility.

**Slashing Data and Analysis**

Using the average slash depth and samples thickness, the severity of any slash can be expressed as a percentage. An untreated piece of vegetable tanned leather provided a control. This set the baseline slash depth at 81.7% of the total thickness, cutting 2.575mm through the 3.15mm sample. Deviations in the slashing depth percentage were attributed to the particular physical qualities of each sample. The top-performing sample in this test was S8b (100.60.0.0) with an average slash depth of only 9.6%. The worst performing sample was S11b (15.60.1.0), which was cut in
half. This effect was observed in four instances. The average slash depth of samples which were cut in half is recorded as the thickness of the sample at the initial point of impact. Thus, samples cut in half have a slash depth of 100%. It should also be recognized that only three of ten boiled samples could be tested. By the time I arrived at this final challenge, both $A$ and $B$ samples of each recipe had been destroyed in previous tests. Their irregular shape could not be tested using my rig.

**Table 7.3:** Ranked slashing with scores assigned.

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<thead>
<tr>
<th>SAMPLE NUMBER</th>
<th>IDENTIFIER</th>
<th>Temperature Map</th>
<th>Time Map</th>
<th>Bake Map</th>
<th>Wax Map</th>
<th>SLASH DEPTH AS PERCENT (%)</th>
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* Sample was cut cleanly into two pieces.
Water Immersion/Boiling

Samples that were treated with 15° or 55°C water immersions had equal slash resistance. The most severe case within this group was S1b, which was nearly cut in two. Its average slash depth of 3.08mm cuts through 97.5% its total thickness. For S2b-S6b, the accumulated cuts slashed 80% through on average. While none of these samples were dismembered, most were irreparably damaged by the laceration. The halves clung together only by the lower corium layers and could be easily creased on this fissure. With continued wear, they would inevitably split [Figure 7.11].

Of the three boiled samples able to be tested, a peculiar picture emerges. S7b is only cut 0.75mm deep on average -- 20% of its total thickness [Figure 7.12]. Even more remarkable is S8b, which gathered scratches merely 0.375mm deep -- less than 10% the total thickness. In these cases, the blade was almost completely neglected by the leather plate. Even at the sample edge where more severe cutting tended to occur, the boiled samples were never gouged more than 1mm deep. S16b, the third boiled sample, is likewise slashed only 18% through its total thickness. By a vast margin these three boiled samples occupy the highest performing ranks in this challenge.

Clearly, the surface hardness of boiled \textit{cuir bouilli} makes it extremely resistant to cutting. They sustained mostly superficial damage in the form of hairline scratches, but were not otherwise broken or damaged. Among these three surviving samples, two were only boiled for 30 seconds and one was boiled for 60 seconds -- none for the full length of 90 seconds. It might be tempting to extrapolate the performance of these three to the untested seven. As far as touch can discern they
seem to be roughly equivalent. However, my inability to test these seven is telling in itself. For armor to be of meaningful benefit, it must be able to withstand reasonable (or unreasonable) abuse. If the sample could not survive the initial two test, it was eliminated from the third. For boiling to be of functional use, it must be not be overdone. The surviving samples retained a degree of plasticity, providing the toughness and durability to complement surface hardness. These characteristics were more readily produced using mild boiling treatments.

**Baking**

Baking was found to have a detrimental effect on most samples’ resistance to slashing attacks. Of the six samples that were baked, but not boiled previously (S10b-S15b), four were cut completely in half by a single slash [Figure 7.13]. They have a slashing depth percentage of 100% as a result. This trend seems to be comparable to the performance of baked samples in arrow piercing. The dryness of the fibers might be more easily torn or frayed, making the leather weak to cutting. The remaining two in this condition performed marginally better than their unbaked analogs. For these samples, it is perhaps possible that the minute contraction and compaction of the leather fibers produced cutting resistance. Nevertheless, these differences are slight. When averaged as a group, baked *cuir bouilli* was the poorest performing in this test. The final baked sample, S16b, did exceptionally well in this tests. However, as previously explored, this success is more likely attributed to its boiled condition rather than subsequent baking
**Beeswax**

Other than the three outstanding boiled samples, those saturated in beeswax demonstrated the highest resistance to slashing attacks. Of the samples which were waxed, but not boiled nor baked previously (S19b-S24b), the slashing depth was only 59% of the total sample thickness on average [Figure 7.14]. When compared to unwaxed S1b-S6b, the marginal differences in protection provided by beeswax stuffing can be isolated, indicating 20% greater slashing protection. Curiously, the samples that were baked and waxed, S28b and S29b, were even more effective, but only slightly.

Although statistically none of the waxed samples performed as well as the boiled samples able to be tested, their resilience might also be considered. Wax stuffed samples, if not previously boiled, showed no signs of brittleness and adapted readily to abuse. When slashed, they did not gouge as severely as unwaxed leather. Much of the corium remained intact. Thus, the damage they sustain is more easily managed and does not compromise the greater structural integrity of the plate. As consequence, waxed *cuir bouilli* might be more sustainable -- requiring less repairs and replacements than boiled or baked counterparts [Figure 7.13].
Chapter 7 Figures:

Figure 7.1: S6a, the highest performing sample against arrow penetration, formed a tight seal around the arrow upon impact, gripping the arrow until it was slowed to a stop.

Figure 7.2: Arrows caused minimal damage to unhardened samples, leaving only frayed holes that did not compromise the overall structure.
**Figure 7.3:** S9a (100.90.0.0) was severely shattered by the arrows offering no further resistance to arrow penetration.

**Figure 7.4:** S7a (100.30.0.0) also offered poor protection against arrow penetration, but was not thoroughly destroyed in the testing process. Milder boiling treatments might retain a degree of elasticity and toughness.
Figure 7.5: S28a (15.60.1.1) offered poor resistance to arrow penetration, similar to boiled samples. Nevertheless, the beeswax offered toughness to these samples and they accumulated minimal damage.

Figure 7.6: Control drop using only the padded blanket (gambeson). This provided a baseline impact that all samples could be compared to.
Figure 7.7: Graphical impulse map for S1b (15.30.0.0), the poorest performing sample in the impact resistance test. The impulse spikes detected with this sample are almost identical to the control.

Figure 7.8: S9b (100.90.0.0) was the top performer in the impact resistance test. Its peak impact impulse is only half as high as the control or S1b. Moreover, this impulse occurs over a longer duration of time, indicating that the sample is dispersing the energy across its surface, reducing its focus.
**Figure 7.9:** S15b (55.90.1.0) exhibited some marginal impact protection compared to unbaked comparisons. However, its protection was not as substantial as boiled samples.

**Figure 7.10:** S21b (15.90.0.1) provided substantial impact resistance due to its beeswax treatment, deflecting 300N compared to the control. While waxed samples still do not offer as much protection as boiled samples, they are far more durable.
Figure 7.11: S1b (15.30.0.0) was cut 80% through its entire thickness. While it was not the poorest performing sample, it lacked significant slashing resistance. Moreover, the deep slashes weaken the piece as a whole, making it more likely to tear with continued use.

Figure 7.12: S7b (100.30.0.0) demonstrated excellent resistance to slashing attacks. Its profound surface hardening easily turned the edge of the blade, accumulating only minor gouges near the bottom of the sample.
**Figure 7.13:** S11b (15.60.1.0) was one of four samples cut cleanly in two by the slashing test, demonstrating very poor slashing resistance.

**Figure 7.14:** Waxed sample S22b (55.30.0.1) was cut nearly 60% through its total thickness. Though as severe as unwaxed or baked samples, boiled samples still outperformed waxed ones. Nevertheless, the wax provided additional structural support, diminishing the effects of accumulated damage.
Chapter 8: Implications of *Cuir Bouilli* Performance

As the performance of *cuir bouilli* samples in three previous tests indicate, hardened leather may indeed have provided an armor benefit against the attacks that characterized medieval battlefields. To briefly summarize this performance, boiling was found to be highly effective at resisting blunt trauma and slashing attacks, but was prone to breakage. Beeswax treatments exhibited hardening effects that also resisted impact and slashing. These samples generally offered a slightly lesser degree of protection, but were not hindered by the brittleness that characterized boiled *cuir bouilli*. Baking had only minimal armor benefits, exhibiting minor resistance to impact, but poor performance against slashing and arrow piercing. Curiously, unhardened leather demonstrated the best protection against arrow piercing. Boiled and waxed samples all allowed greater arrow penetration than samples that had not received these treatments.

While certain samples demonstrated a high performance in individual tests, there were very few which provided adequate protection in all three categories. S28 (15.60.1.1), with an overall score of 75 out of 90 possible points, was the top overall performer. This sample demonstrated exceptional protection against impact and slashing, and better than average resistance to arrow penetration. The top performing samples that followed collected aggregate scores of only 60 points. These samples generally exhibited high performance in two tests, but suffered from distinct weaknesses against at least one type of attack. For example, S16 (100.30.1.0) was a
top performer in impact and slashing trials, but provided only minimal protection against arrow penetration.

Table 8.1: Final ranked *cuir bouilli* performance after three tests.

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<th>SAMPLE NUMBER</th>
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<th>Time Map</th>
<th>Bake Map</th>
<th>Wax Map</th>
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<th>SLASHING SCORE</th>
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Thus, it appears that the properties that would characterize an *ideal* sample, able to deflect all attacks, are at odds with one another. Rigidity is necessary for protection against impact. This allows the force of the blow to be dispersed across the surface of the plate, decreasing its focus and minimizing trauma. Surface hardness is the essential quality for slashing protection, allowing plates to turn the edge of a blade. Boiled samples, demonstrated the highest resistance to both of these types of attacks, but at a cost. Their rigidity and hardness, while protective, makes them susceptible to fractures that detract from their ensuing performance. Almost all boiled samples, regardless of additional treatments, were destroyed by the end of testing. Waxed samples suffered the least permanent damage from all tests. The elasticity afforded by beeswax saturations gives the leather tenacity to withstand abuse and accumulate damage without apparent deficits in performance. Nevertheless, these samples are inherently less rigid than boiled *cuir bouilli*. Their durability is at the cost of protection.

The matter of arrow protection is perhaps the most intriguing. Samples that were most like the original, untreated vegetable tanned leather functioned most effectively at arrow defense. These samples retained the highest degree of elasticity and were not characterized by significant shrinkage or hardening. When struck by an arrow, the leather formed tight seal around the shaft. This gripped the arrow as it passed through, providing the most friction and, ultimately, reducing the depth of penetration. Samples with superficial rigidity and hardness provided negligible resistance to arrow penetration. Boiled samples shattered upon initial impact, offering no further resistance. Waxed samples lubricated the arrow. This decreased in friction
negated any ability to slow the arrow and minimize penetration. Hardness, it seems, is only useful if the arrow can be entirely defeated by the armor, unable to fully penetrate the plate. If hard enough, the arrow could, hypothetically, bounce off the plate with minimal inflicted damage. Indeed, this was one of motivations that drove the development of metal plate armor. Unfortunately, I believe this ability is beyond the capabilities of cuir bouilli and may be a crucial reason it was eventually superseded by metal plate.

It must also be understood that my experiment does not demonstrate every possible quality cuir bouilli could have possessed in its varying iterations. My sample group of 30 unique recipes is not comprehensive. Rather, it isolates the variables crucial to the production process and seeks to draw easily identifiable trends about their effects. As a result, the variables manipulated, water temperature especially, are exaggerated in hopes of revealing these trends.

As the data demonstrates, these trends did manifest in the results. All advantages and disadvantages of treatment methods are extrapolated from this data. Nevertheless, my methods did not necessarily produce samples of the highest attainable quality. Doing so would require greater experience with the medium and the ability to take nuances of this natural material into account. Moreover, these independent procedural modifications would compromise the objectivity of my experiment. Though these refined methods are not realized explicitly within the scope of my study, the trends discovered offer directionality to these ideals.

This is most immediately applicable to boiling treatments. Boiled samples exhibited excellent performance in certain applications, but suffered from brittleness
overall. The three boiled samples that survived into the third (slashing) test were all prepared using the lower end time prescriptions, only 30 or 60 seconds. Thus, it might be inferred that boiling for slightly shorter lengths of time, or perhaps at lower temperatures, will produce *cuir bouilli* that is both hard and resilient. Lingwood especially advocates the use of such methods. With the data collected from my experiments, proof is offered that this is a necessary prescription and worthy avenue of continued investigation.

It is my hope that the trends elucidated here will inspire continuing attention to these methods. Using this data as a foundation for future studies, future iterations of experimental *cuir bouilli* production might be able to identify exemplary preparation procedures while still maintaining historic viability. Now that the general effects of these treatments are realized, greater attention might be paid to the specifics of each. Thus, future experiments should include additional treatments not explored here, but which extrapolate from these trends. Now that it has been shown conclusively that 100°C water has potential armor benefits, but is paired with certain disadvantages, the effect of exactly shrinkage threshold temperatures (75-85°C) would be of particular interest.

While further investigation of *cuir bouilli* preparation procedures might enhance its performance, I would also propose that there cannot be an *ideal cuir bouilli*. As I have discussed, the characteristics that would provide the most comprehensive protection cannot be realized simultaneously. Moreover, the effectiveness of any armor is situationally dependent. The tests I conducted were all generalizations of medieval weapons attacks. While my tests were designed to
measure the essential effects of three basic categories of weapons, they do not represent effectiveness against any specific typology of weapon: such as a scimitar, Oakeshott type XVIII sword, or seax to name a few contrasting examples. In a historical battle scenario, the distinct performance of each weapon would have pronounced itself more clearly. Thus, certain recipes that appear to be effective at defending generalized attacks might be more or less effective in actual use.

As a result, the range of preparation procedures and the defensive characteristics they exhibit might be adjusted according to anticipated usage. If it were known that a certain enemy utilizes particular types of weapons, the preparation of cuir bouilli armor elements might be tailored in response. The ideal cuir bouilli armor is only ideal within the context it was conceived. What works most effectively in one region and time might be entirely unreliable in another. Since cuir bouilli appears to be more effective at defending against impact and slashing, it might have been most useful to infantry soldiers who engaged in most of the hand-to-hand skirmishes. Any exposure to ranged arrow attacks, however, would be irrepressible.

Furthermore, without surviving examples of cuir bouilli its specific usage as armor is conjectural. While visual images might appear to depict cuir bouilli, none of these interpretations can be asserted with absolute certainty. Nevertheless, analysis of armor images produced during this transformative period of armor development might offer suggestions of its usage. Cuirasses, greaves, and rerebraces have all been proposed as likely employments of molded cuir bouilli armor. It is essential to realize that the emergence of cuir bouilli defensive elements could not have replaced the established costume of chain-mail hauberks and padded gambesons. The long-lived
use of chain-mail demonstrates that metal armor was already known and in use centuries before medieval explorations in *cuir bouilli*. Rather than, acting as a substitute for these proven armor components, I believe *cuir bouilli* would have been most effective in addition to them. Soldiers might have affixed *cuir bouilli* on top of existing hauberks and gambesons (though under surcoats as some images suggest). Any supplementary addition of *cuir bouilli* to this costume could only have enhanced the protective value, offering marginal increases in defense reflected in the tests I have conducted. Moreover, these experimental *cuir bouilli* armor elements might have served as prototypes for later plate armor.

The protective attributes of *cuir bouilli* armor might not have been its only attractive feature. This is best illustrated by the weight of the *cuir bouilli* horse crupper discussed previously, only 2.13kg, in comparison to a crupper of similar dimensions made of iron, which weighs a full 6.77kg -- three times as much (Waterer 1981: 75). When a full suit of armor is considered, the differences in weight would have been even more pronounced, potentially approaching tens of kilograms! The considerable differences in weight might be enhanced by the semi-elastic quality certain varieties of *cuir bouilli* retain. This would have allowed plates to bend moderately in compliance with the body of the wearer. As contemporary studies have demonstrated, the cost of locomotion while wearing metal plate armor is twice as high as unburdened movement.54 The immense burden of metal plate greatly impairs

54 This study examined the mechanics and energetic costs of locomotion while wearing armor to determine its effects on physical performance. Individuals were equipped with full replica suits of metal plate armor based on 15th-century English, Italian, and German models. Test subjects then performed physical endurance tests such as running and walking on a treadmill, during which vital signs like heart rate and respiratory volume were measured. It was determined from this data that the energy costs of locomotion while wearing a 30-50kg suit of armor were twice that of unburdened baselines. The effects of this weight are amplified with age (Askew et al. 2011).
movement. It thus seems likely that the comparatively low weight of *cuir bouilli* armor would have allowed much greater mobility and better endurance, providing a distinct advantage against an over encumbered enemy.

It has also been suggested that *cuir bouilli* armor, if damaged, would have caused less agitation to a wounded warrior than metal plate models. If pieced by an arrow, the interior face of metal plate would bear jagged edges that could aggravate an already tender wound (Waterer 1981: 76). *Cuir bouilli* plates, when damaged, are not characterized by these sharp barbs. The fibers of the leather tear and fray, producing a relatively softer edge less likely to irritate the wearer [Figure 7.2].

Perhaps the most attractive characteristic of *cuir bouilli* armor, in comparison to metal plate, might have been its cost. Leather being a much more readily accessible material than forged metal plate, it could have provided an effective armor solution for lower income foot soldiers as opposed to mounted knights. This would have been particularly applicable to soldiers who were not subsidized with issued equipment and expected to furnish their own arms and armor. *Cuir bouilli* might have continued to exist in this context long after being eclipsed by more effective metal plate armor. Even if unable to withstand the full extent of battlefield abuse, *cuir bouilli* armor does undoubtedly provide some degree of protection which might have been welcomed by soldiers without a superior option. Thus, it might have become the armor that characterized nonessential personnel, perhaps even horses as the crupper suggests.

It should also be considered that contrasting varieties of *cuir bouilli* would have been used simultaneously within a single costume, taking advantage of the unique strengths of each recipe to provide more comprehensive protection. Boiled,
waxed, and even untreated leather might have been layered, providing greater protection than any could have offered alone.\textsuperscript{55} A coat-of-plates might be most representative of this model, using layers of leather or metal to form a highly functional laminated armor. If unhardened leather were layered with boiled \textit{cuir bouilli}, it could have provided greater protection against arrow penetration especially, though this suspicion needs further testing to be confirmed.

Boiled leather might also find functional comparisons in modern body armor. As elaborated in earlier sections, boiled samples were especially prone to shattering. However, as the impact data revealed, samples that fractured provided the most effective protection against blunt trauma attacks (S9b and S26b). While modern soft body armors such as kevlar are effective at stopping fire from small arms, a more robust defense is needed to stop larger projectiles. Modern body armor uses heavy ceramic plates to defeat higher energy rifle rounds. When struck by a bullet, the plate shatters in a dramatic dissipation of energy, but stops the projectile nonetheless. These plates are one time use. After serving their purpose, hopefully saving the wearer’s life, the plate cannot be repaired and must be replaced. However, this ability to shatter provides a ready avenue for the immense energy to be dissipated and is crucial to the armor’s performance (Hansen 1969). This property, I believe, is reflected in the performance of boiled \textit{cuir bouilli} samples, which provide ample

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\textsuperscript{55} This usage, I believe, might have functioned akin to modern laminated bulletproof glass. Safety glass produced today uses alternating polycarbonate layers with dissimilar compositions to achieve functional strength greater than the sum of its parts. Top layers are hard, but brittle and shatter easily upon impact. Middle layers are much more plastic and resilient; rather than cracking or breaking, they stretch or bend. When struck by a bullet, the brittle layers shatter but knock down the velocity of the bullet tremendously in this instant. The bullet is able to penetrate these outer layers, but is caught by the inner core of elastic polycarbonate. These inner layers deform, dispersing the energy of the bullet until it is slowed to a stop (Beckman et al. 1972). By increasing the thickness or number of these layers, the strength of bulletproof glass can be adjusted to even stop high power rifle cartridges. This property might have been explored with \textit{cuir bouilli} armor.
protection despite their accompanying damage. While it might be necessary to replace plates of boiled leather after heavy use, they function suitably in the moment of need.

Finally, my study of *cuir bouilli* cannot be the final word on the subject. It has provided what I believe to be objective and empirical evidence of the material qualities and practical uses of *cuir bouilli*. Despite this, any experiment requires exhaustive to confirm these findings. Within the discipline of experimental archaeology, repetition has always been a tricky aspect. Repeated experiments have frequently produced augmented results (Coles 1979: 40). It is my hope that the explicit methods that characterized my process will promote a further investigation by others interested in medieval leather craft. Future studies are necessary to corroborate my findings, bolster, or overturn the case for the usage of hardened *cuir bouilli* armor.

My own experiment was laboratory based and sought to control variables in search of material objectivity. It is most clearly aligned with the approaches of processual archaeology and middle-range theory that make exhaustive use of analogs. However, the positivism of studies like my own has come under scrutiny in recent decades. Post-processual theory emphasizes the subjectivity of archaeological processes (Johnson 2010: 105). A field study that relaxes the control of variables in search of greater situational authenticity might provide necessary contrast to my findings (Ferguson 2010: 6). Such a study might begin with leather tanned using authentic medieval methods (perhaps tanned by experimenters themselves) and utilize treatment methods that abandon the rigid instructions I maintained. Thus, the crafting methods specific to each typology of *cuir bouilli* might be explored with honest intuition and closer aligned to their actual historical use.
Works Cited


Cushing, Frank Hamilton. "Primitive Copper Working: An Experimental Study."


Lingwood, Rex. "JOHN WATERER AND THE 'CUIR BOUILLI' CONFUSION."


MacGregor, Arthur. "Hides, Horns, and Bones: Animals and Interdependent


Print.


Print.


Print.


Stambolov, T. *Manufacture, Deterioration, and Preservation of Leather: A Literature Survey of Theoretical Aspects and Historic Techniques*. Amsterdam: Central


