Blade Patterns Intrinsic to Steel Edged Weapons

by Lee A. Jones

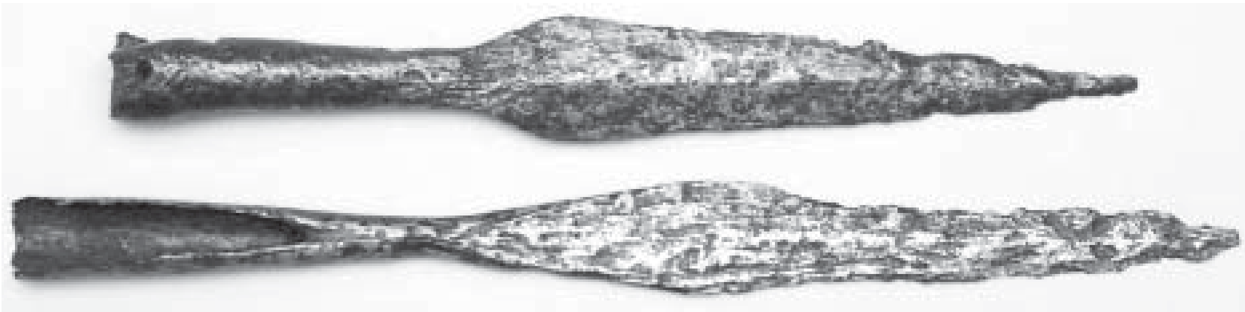
In examining objects made from modern industrially produced steel little or no texture is readily apparent to the naked eye, even if the objects have been weathered or corroded. Earlier iron and steel artifacts will frequently show a pronounced texture. Such textures may arise from heterogeneous composition and or impurities such as slag stringers that are banished from or tightly regulated in the production of modern steels. Additionally, in the case of antique edged weapons, smiths frequently manipulated naturally occurring textures and or ingeniously joined together dissimilar materials to achieve desired performance and or aesthetic appearance. Whether deliberate or intentional, such patterns often yield clues to how such items were made. This article will show a sampling of such patterns as are found in swords and other edged weapons from a diversity of cultures and times.

In considering the following series of examples it is recommended that the reader consider four admittedly artificial and arbitrary parameters, as each may be present to some extent in many examples. The first will be the natural texture or grain background of the material such as arises from slag inclusions as seen in wrought iron or from natural crystalline structural heterogeneity as in *wootz* (true Damascus) steel. Second will be grain structures that are modified by a bladesmith in layering and folding the raw material back upon itself either a few or many times and whether solely for mechanical benefit or for deliberate aesthetic effect. Third are forging effects and manipulations undertaken by a smith to distort the natural background grain and layering to produce a desired pattern. Important to consider within this parameter for layered structures will be the planes of subsequent stock removal (grinding) and how the angle of intersection of the created surface interacts with the existing grain and layer structure to form a visible surface pattern. Fourth are the further effects obtainable in a blade made up of several components welded together, whether it be merely a piled structure necessary to achieve the desired blade mass and perhaps never intended to be noticed by the customer or a deliberate decoration. The term 'pattern-welded' or 'twist core Damascus' is applied to a technique exemplified in Europe by Migration Period and Viking Age swords, but also seen in work from many cultures in Asia. An extreme of this final parameter in the welding together of many components will be exemplified in a chevron-pattern Indian blade.

Natural Grain and Texture

Wrought Iron

The vast majority of pre-industrial iron came from the bloomery process. Prior to the 13th to 14th century, the charcoal-fired furnaces used for the reduction of iron from its ores could rarely attain a sufficient temperature to actually melt iron (and when they accidentally did, the resulting brittle metal mass was useless to the technology of the time). The desired result was a spongy mass of malleable iron termed a 'bloom' that also contained some residual entrapped slag and a greater now separated mass of slag waste including silicates,



Excavated European early medieval spearheads. These would have been made of bloomery iron and likely subsequently carburized to create a harder steel surface. The slag impurities revealed by corrosion in early steel from direct (never molten) bloomery iron are usually less uniform in size and distribution than in wrought iron made by the later indirect method (molten to cast pig iron which was then decarburized).

unreduced ore and other impurities. Composition and quality could vary significantly between batches owing to factors unrecognized or inexplicable at the time. Occasional blooms might naturally include steely areas (where sufficient, but not excessive, carbon was incorporated into the iron). Such material could often be recognized by a smith and reserved for cutting edges. Steel could also be deliberately produced from bloomery iron by subsequent carburization (an increase of carbon largely by diffusion from adjacent carbon rich material) in a charcoal furnace. From the 14th century, with increasing adoption of the blast furnace, purer iron would be produced at higher temperatures by melting iron from the ore to create brittle cast or pig iron. A subsequent process then reduced the high carbon concentration in this material to form wrought iron. Processes discovered by much trial and error augmented by superstitions understandably preceded the gradual scientific understanding of the nature of steel of the past few centuries.

In the processes of fabricating wrought iron into the semi-finished forms supplied by a mill, whether by hammering or rolling, a texture arises as the remaining impurities move along with the metal forming elongated stringers. Etching or corrosion of such material will reveal a ‘fibrous’ texture analogous to what is seen in sections of wood: cuts parallel to the grain structure will show a straight pattern, curved cuts across the grain will show a complex wood grain-like pattern and cuts perpendicular to the grain structure will show an end grain pattern.

Battle-axe head created by Dan Maragni in 1980 by grinding a bar of quality Victorian era wrought iron to desired shape with the pattern revealed by subsequent acid etching. As the angle of the bevel increases towards the edge, the texture changes to an oblique end grain. The darkened steel cutting edge seen to the right was welded in place, an ancient and common practice to conserve expensive steel.

Wootz Steel (True Damascus)

Wootz is a particular sub-type of crucible steel originating in India and most famously used in Islamic arms and armor for its attractive surface appearance and an ability to retain a sharp cutting edge. *Wootz* was produced by heating iron ore, charcoal, and vegetable matter in a crucible for a prolonged period of time. This would produce a relatively pure and fairly high carbon steel, indeed sufficiently high carbon that special handling was necessary in forging the blade if fractures were to be avoided. The secrets of *wootz* were long considered lost as a consequence of the disruption of the local traditional Indian production during the British colonial era and only in the last few decades has convincing *wootz* been recreated.

These blades were directly forged from a small cake of this heterogeneous steely iron. J. D. Verhoeven, et. al. (1998) propose that microsegregation of carbide-forming trace impurities, particularly vanadium and manganese, in the source ore results in carbide banding. Restrained forging at relatively low temperatures is necessary to preserve and

Indian *katar* (*jamadhar*) of the 18th century with an exceptional *wootz* pattern; the best work features bold patterns with high contrast such as seen in this example. This wavy pattern of shiny and dark steel is made up of networks showing different metallographic structures (specifically globular cementite in a matrix of pearlite) and extends through the full thickness of the blade, appearing similar at any angle of intersection with the varied surfaces. Foci of a cast crystalline dendritic structure appear to have been retained in this blade indicating very restrained forging and stock removal to create the high central rib and other topographic features.

An Arab style *saif*, early 20th century, mounted with an earlier Persian *shamshir* blade. The 'watered steel' pattern is typical and reflects a dendritic pattern distorted by forging. The light areas in the pattern represent iron carbide (cementite) with a carbon content similar to cast iron imparting hardness and excellent cutting ability (at a cost of brittleness) set in darker material (pearlite) of more malleable 'normal' steel imparting toughness and resistance to shattering.

enhance the pattern. Following final grinding the pattern created by this natural heterogeneity of the steel is exposed by mild etching. Customers for sword blades in the Middle East reputedly particularly valued a type of pattern referred to as *kirk narduban* or the ladder of the Prophet. While many explanations have been put forth in the literature as to how this was most difficult to achieve, such a pattern is, in fact, easily achievable by filing notches into the incomplete blade perpendicular to its length at regular intervals subsequent to a final forging to flatten the surface.

Most crucible steels do not produce such macroscopically visible patterns. Recent metallographic studies suggest that the best of the European Viking Age Ulfberht blades may possibly have been forged from imported Asian crucible steel (Williams, 2003).

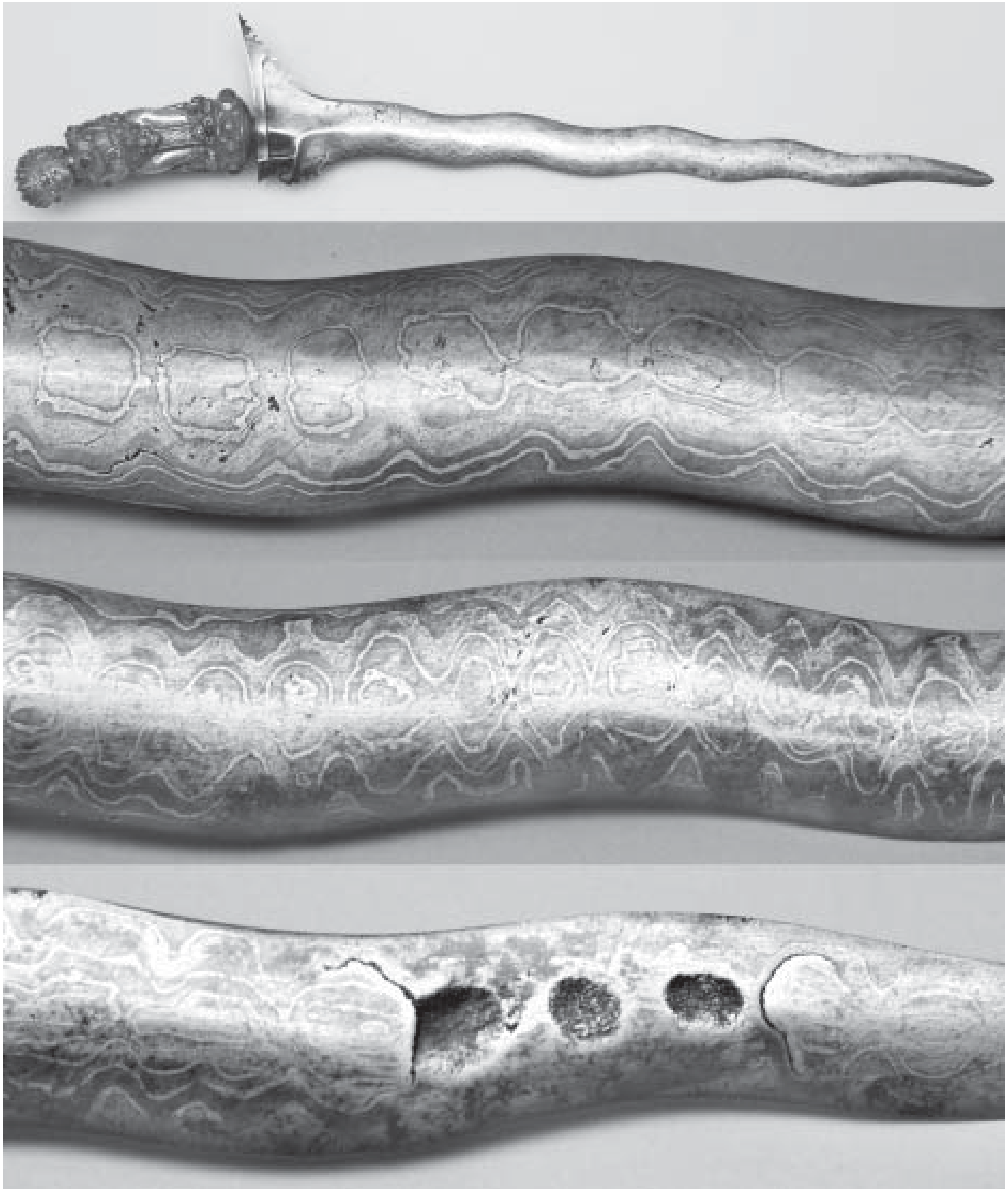
Kurdish *kard* with mountings from the early 20th century and a blade cut down from the forte of a fine Persian *shamshir* signed Kalb Ali and dated 1181 AH (1767-1768 AD). The close-up of this blade shows the *kirk narduban* (Mohammed's ladder) pattern with several 'rungs' (above arrows) oriented perpendicular to the length of the blade representing an induced alteration in the background pattern.

Balinese *keris*, probably earlier 20th century, with a blade *pamor* formed by coarsely laminated contrasting steel alloys. In this case, the layers are oriented parallel to the plane of the blade (*mlumah*) and have been intentionally manipulated to intersect with the ultimate etched blade surface to create the pattern.

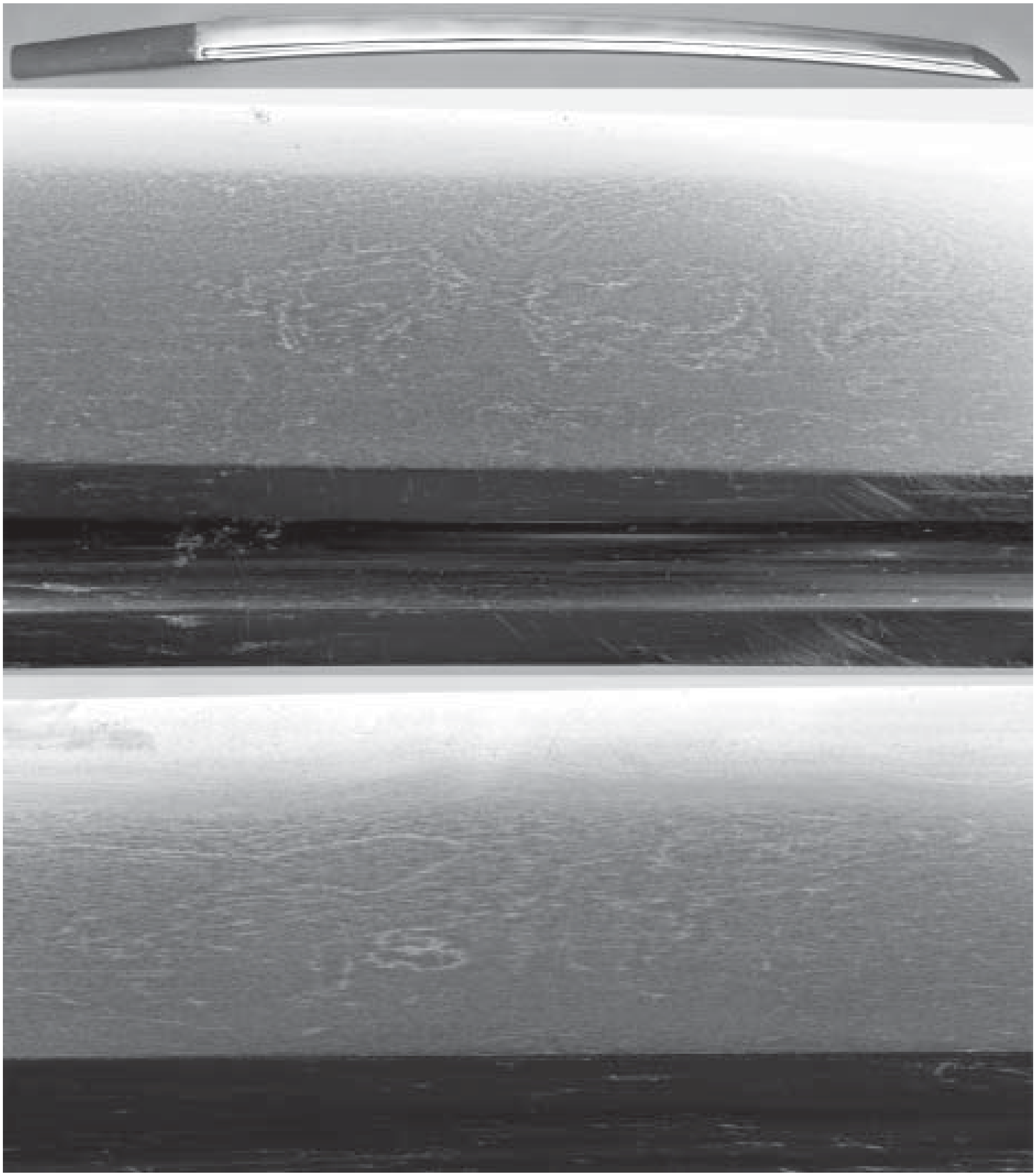
Coarsely Laminated Steel

Pamor of the Keris

The *keris* is a type of edged weapon characteristic of the Malay peninsula, Java, and other areas of the South Seas. The above photograph of a *keris* blade discloses patterns (*pamor*) upon the surface which also reflect the internal structure of the blade. These swords were made up of a billet composed of alternating layers of steel and of iron containing nickel. In earlier blades, the nickel alloy came from meteoric material while artificial alloys have frequently been used since the 19th century. The patterns may have an appearance resembling contour lines as seen on a map or weathered geologic strata seen from the air. To create this pattern the contrasting materials are welded together in sandwich fashion and then folded back over upon themselves a few times to yield a few thousand layers (six folds in the example given by Solyom (1978), p. 9 - 10). Even if no deliberate attempt was made to mechanically influence the pattern achieved by deforming the layers, the process of manual forging will result in irregularities of the thickness of particular layers in different parts of the blade. The pattern achieved from the final grinding will depend upon how the newly created surface intersects with the layers. In the photograph above, the layers are nearly parallel to the blade face, undulating mildly, so that when ground, wide bands of contrasting metal are seen. Towards the central spine and edges, where the plane of stock removal cuts across the layers more acutely, the bands appear narrower. Many different patterns can be achieved by manipulating the blade before final forging and grinding. Drilling shallow holes into the incomplete blade and then forging the area flat results in bull's eye-like structures. Other blades show structures built up by lines engraved into the material before it is again forged flat and then polished, exactly analogous to the *kirk narduban* of Persian and



Another Balinese *keris,* probably later 19th century, with a blade *pamor* formed by relatively coarsely laminated contrasting steel alloys, the lighter steel containing nickel for sharp contrast. Aesthetics in Bali lean more towards a polished blade, such as this example, than the etched surface currently favored in Java. In this example, the layers are again oriented parallel to the plane of the blade (*mlumah*) and have been intentionally distorted by shallow holes or punch work prior to the surface being reforged flat to create the pattern. Repeated cleaning and polishing have disclosed a once hidden zone of failed weld adherence (cold shut) between two layers and depressions are now left where the surface has fallen away over the defect. Adjacent cracks foretell further surface losses should the blade be polished again.



Japanese *wakizashi* ex *tachi* with foci of *mokume* (burl) *hada* (grain) in a predominant background of *itame* (wood) *hada.* This mid to late Kamakura era Aoe school blade lost its tip in antiquity and therefore has seen fewer subsequent polishings; the polishing technique (*hadori*) masks the true *hamon* ('temper' line).

Indian blades. *Keris* may also show a piled construction or twisted rod pattern-welding exactly as that seen in European Migration Period and Viking Age blades that are discussed below.

Finely Laminated Steel

Japanese sword blades show a variable grain structure which arises as a result of folding the billet from which the sword is being formed back upon itself many times (up to, but usually fewer than twenty, which would give just over a million layers). The concept here is simple: when dealing with steel of varying composition, maximum strength and reliability may be achieved by averaging weak and strong areas by forming a laminated structure. The repeated working will also partially exclude and break up larger slag inclusions, further reducing potential seeds for failure. The close-up photographs on the preceding page show the grain (*hada*) of a 13th century sword that lost its tip in antiquity and which therefore has seen fewer subsequent polishings with the compensation of retaining more surface steel. This *hada* of moderately fine wood grain-like pattern was exposed as the sword was ground and polished and represents a tangential cut through many layers of steel just as the wood grain in a tabletop represents tangential cuts through a tree's growth rings.

A recent study (Mäder, 2009) involved the polishing of some European early medieval (6th - 8th century) blades by a skilled Japanese polisher. It should not be surprising that a fine grain (*hada*) structure very similar to that characteristic of Japanese swords was revealed, as many cycles of heating, flattening, folding and forge welding are the best way to optimize the quality of steel originating from bloomery iron.

Differential Heat Treatment

Below is a photograph of a Japanese *tanto* (dagger) blade from the 17th century. In the blade close-up the wood grain-like pattern which results from the many layers of steel making up the blade is again evident. Additionally, a wandering misty pattern of increased brightness (*nioi*) may be seen about one-third to a half of the distance back from the edge which represents the *hamon* or

Nioi appearing as a misty line along the *hamon* in a 17th Century Japanese *tanto* (dagger) blade. As the *hamon* is a boundary formed at the time of quenching, the term 'temper line' is a misnomer.

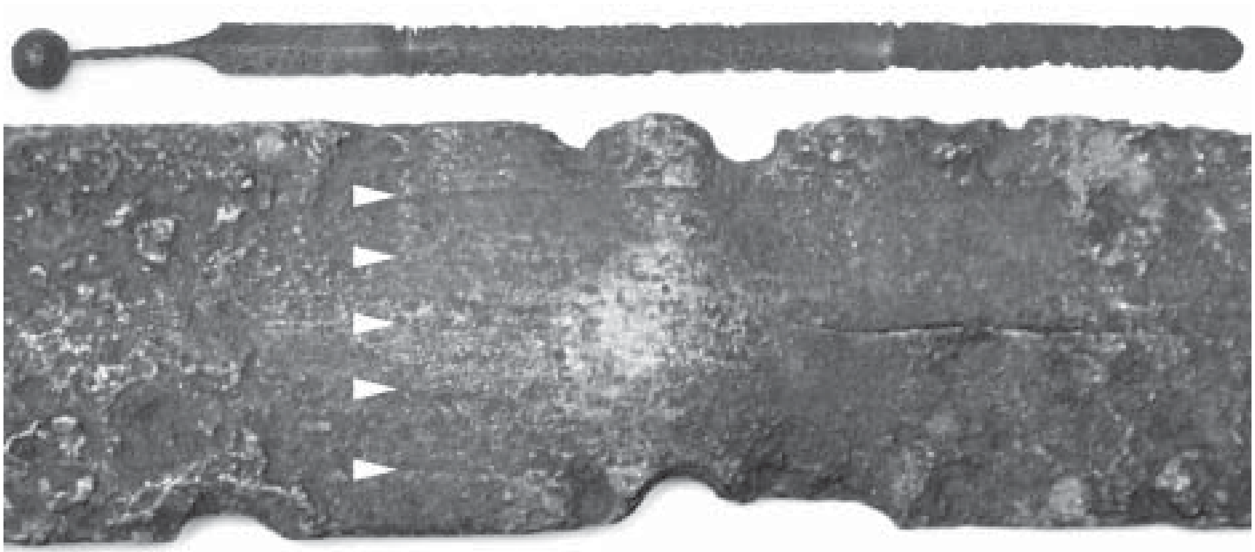
Nie beside the *hamon* in a tired 15th Century Mino *tanto*. *Nie* may be more evident in over-polished blades, as the repeated polishings are exposing deeper areas which would have cooled more slowly when the sword was quenched.

'tempering line' and is composed of a band of what metallurgists call martensite. Larger crystals termed *nie* may also be observed when cooling has been slower or the temperature higher, as have been exposed in the close-up photograph above of a tired (worn from many polishings) *tanto*. In Japanese swords, the differential tempering is achieved by a technique in which the swordsmith applies varying thicknesses of different types of clay to the surface of the blade before it is quenched. Thicker and more insulating clay over the back and body of the blade slows cooling and results in less brittle and more malleable iron there, while the edge cools more quickly and is harder, but also more brittle. In this way, a hard sharp edge may be part of a sword without excessively increasing the brittleness of the entire blade (Kapp, 1987). Thus we see that, aside from its overall form, two of the most critical aesthetic features of the Japanese sword, the nature of its grain and its *hamon*, both reflect appearances that derive directly from the smith's attempts to optimize his material and to produce a strong, durable and highly functional sharp sword.

Complex Constructions

Piled Blade Structures

The polished surfaces of the *nihonto* give scant clue that the majority of traditionally made Japanese swords have been built up from several steels of varying properties, each employed to its best advantage, but this covert construction is critical to the weapon's performance. Cross-sections reveal softer, more malleable steel composing the core of the blade to provide resistance to breakage and the hardest, most sharpenable steel placed at the edge. Other steels with intermediate properties may form the back and the sides of the blade. One flaw (*kizu*) demonstrating the effectiveness of this construction is *ha gire* or a crack perpendicular to the blade's length and through the harder steel of the edge but stopped from further propagation by the softer body or core steel. While this damage renders a blade worthless for future combat use, such a blade could succed, through this ingenious construction, in not catastrophically failing its wielder in a moment of need. Such 'piled' structures most likely initially evolved from

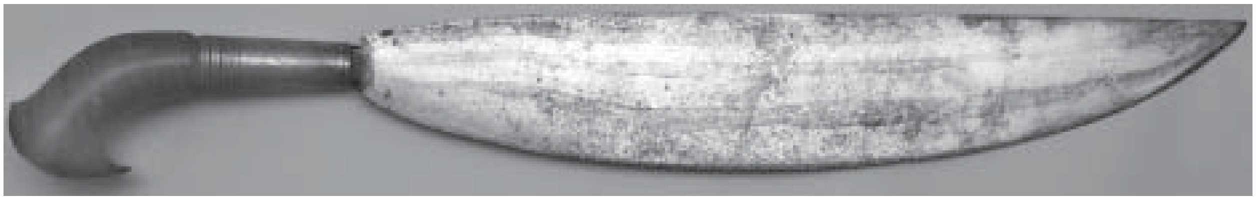


Celtic sword from the 1st century BC, in an area presumably bent prior to inhumation and later straightened. Differential corrosion discloses separate elements for each cutting edge and linearity parallel to the long axis suggests four additional elements in this piled construct (white arrows denote weld boundaries). A parallel stress fracture is seen to the right and appears to be along a welded boundary.

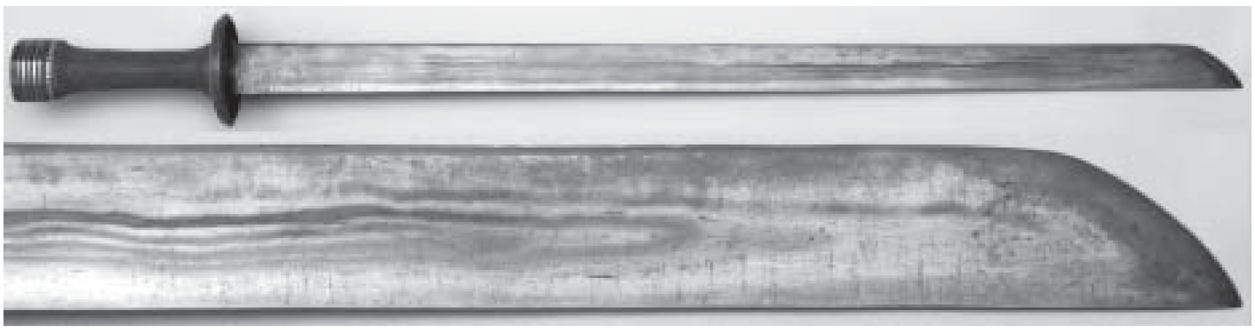
the need of smiths to join together multiple small pieces of steel to form a larger fabrication such as a sword blade. A composition of several rods welded together and running the length of the blade, such piled structures allowed a smith to localize desired properties by empirically joining together irons with differing properties. Additionally, selected rods could be carburized to increase hardness by increasing carbon content. Piled construction provides another advantage in that, like the cycle of heating, flattening, folding and forge welding, it averages the strengths and weaknesses of the individual components lessening the risk of a critical flaw.

Such a construction has been employed in many cultures particularly as they have forged larger, longer blades. In many cases, like the *nihonto*, no special effort appears to have been made to highlight this detail of construction. In some cases, only centuries or decades of natural environmental etching have come to differentiate the components by variation in the developed patina. However, very often etching and differential staining would have be used to develop the patterns as part of the initial finishing treatment of the blade, possibly as an indicator of quality. In many cases such construction has clearly been intentionally further manipulated for decorative purposes.

Pleiner (1993) documents an abundance of variations of piled blade structures in Celtic swords from as early as 500 B.C. In Europe, such piled structures continued to be employed well into the medieval era until improved steels increasingly became available to swordsmiths in later medieval times, after which swords were forged of altogether homogeneous material or had a homogeneous core with only edges of harder material welded on. Evidence of a piled construction is evident upon the surfaces of Tibetan swords and in the sword-*daos* of the adjoining Naga culture, which are regarded as having been imported from Tibet or made from imported Tibetan iron rods in Tibetan style (See Rawson (1968), p. 63 - 64 and figs. 37 & 38).

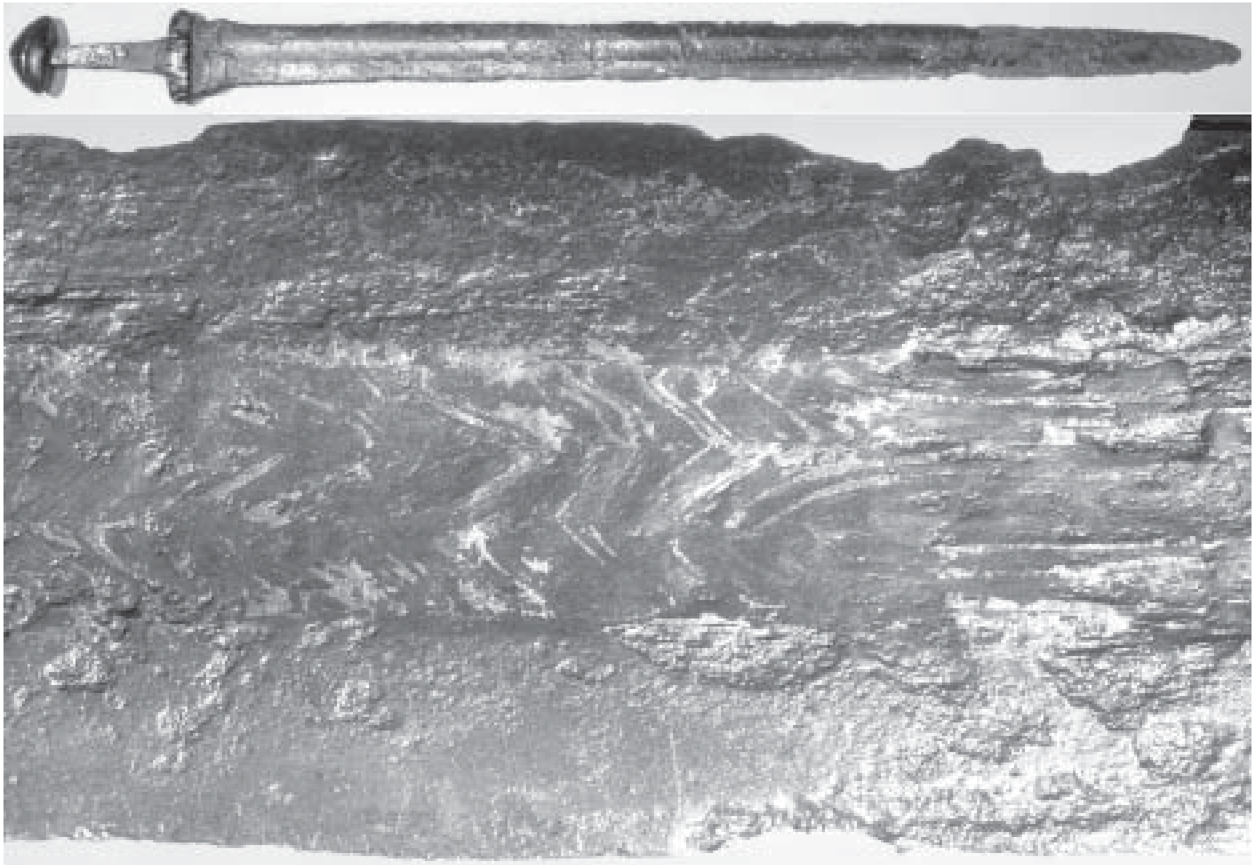


The wide blade of this early 20th century Philippine *barong* shows several bands of alternating contrasting patination which converge at the tip and towards the hilt where the blade narrows. This evidence of piled construction is barely visible on the opposite blade face.



Tibetan *dpa dam* (straight backed saber) typical of the type carried by nomads in the Kham area of eastern Tibet, lightly etched to reveal a type of piled construction in which the body of the blade is composed of a nested set of rods turned back upon themselves at the tip end like hairpins.

Javanese *keris* with a coarse longitudinal *pamor* created by a few thick layers brought out in sharp relief by aggressive etching and or regular acid cleaning. The darker material, being more susceptible to such chemical attack, is roughened and recessed below the lighter, smoother component. The *pamor* appears to be of a class termed *miring* in which laminations are oriented perpendicular or diagonal to the plane of the blade, with their edges exposed at the surface. Considering the relatively few thick components welded together longitudinally, this may be viewed as having as a piled construction.

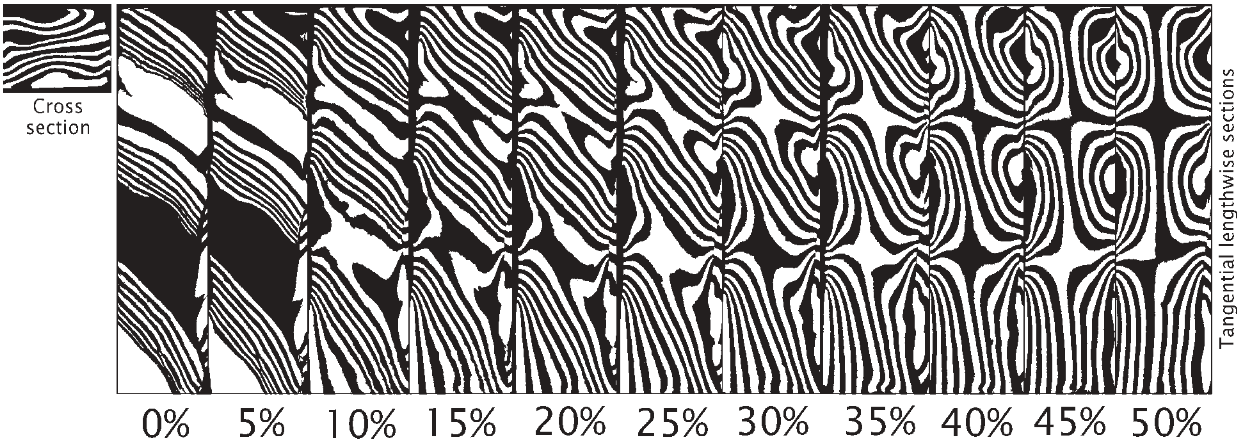


A double-edged European Viking Age (9th century) sword. On the left, the center of the blade is made up of three twisted bands, the central band twisted opposite to those on either side of it, forming a herring-bone-like pattern. On the right, all three bands straighten. Along the entire 74 cm. length of this blade, there are seven such alternations on each side with straight areas opposite the twisted areas on the other side of the blade, indicating that the central patterned area is made up of at least six rods.

Pattern Welding (Mechanical twist-core Damascus)

Occasionally a component rod may have been twisted in a Celtic blade and this may also be occasionally seen in Roman iron artifacts. As the Roman Iron Age gave way to the Migration Period and subsequent Viking Age (5th through 10th centuries), swordsmiths manipulated the piled blade structures to create striking decorative effects. The twisted rod technique by which this pattern has been achieved is called 'pattern-welding'. Essentially all of the patterns identified in these weapons may be built up from rods composed of several, frequently seven, alternating layers of varyingly dissimilar irons (varying depending upon trace elements inherent in the ores of origin) welded together. Depending upon the ultimate pattern desired, these rods would then be twisted either to the left or right or allowed to remain straight along the length of the rod. Rods with matching or complementary twist patterns were ultimately installed side-by-side into the sword blade. Grinding away the outer surfaces of such rods discloses a predictable evolution of patterns which may be further varied by flattening of the rod before it becomes welded to its neighbors in the fabrication of the central portion of a sword from several such rods.

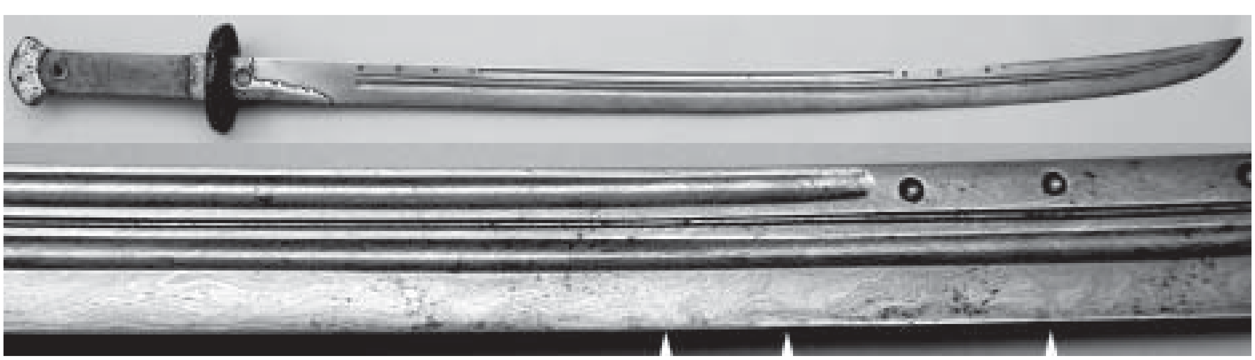
Many authors have concluded that twisting of rods may have excluded additional slag,



Patterns disclosed by successively grinding a facet along the length of a twisted rod demonstrated in a clay model of a rod composed of sixteen alternating layers. The rod has been mildly squared and joined along side another rod, shown only focally at the edge. The rod was then progressively ground and photographed at each interval, reduced in overall thickness by the percentage shown in the scale. Further leveling of the rod will reverse this trend, as a mirror image of these patterns.

allowed a higher carbon content throughout (when the rods were carburized) and distributed strength and weakness throughout a blade in a manner analogous to modern plywood. Earlier blades may well have a cross-section supporting this interpretation, however an evolution seen in later pattern-welded blades towards a thin veneer of pattern-welding over a more homogeneous iron core suggests that, while pattern-welding evolved as a consequence of the piled structure seen in the Celtic sword, in the end it was a purely a decorative technique. Use of the process largely vanishes from western European blades beyond the 11th century. A resurgence came about in the 19th Century as European gun barrel makers began to create complex designs from arrays of tiny component rods for so-called 'Damascus' barrels. Smokeless powder put an end to that fashion, but the tradition has been maintained by several modern bladesmiths. Nickel alloys are most commonly employed to enhance contrast in modern work.

Pattern-welding may also be seen in the many blades of the last several centuries from a surprisingly great diversity of Asian cultures and areas once under Ottoman rule.



Chinese *liuyedao* (willow leaf sabre) of *sanmei* (three plate) construction, probably 18th century, with sides of rather free-form *huawengang* (flower-patterned steel). Occasional 'stars' (above white arrows) are the most overt testimony to a twist core construction for the decorative sides, while the central plate that extrudes to form the edge is higher carbon steel.

A *yataghan*, probably 18th century, characteristic of Turkey and the areas within the influence of the Ottoman Empire. In addition to laminated (layered) steel on its edge and back, the blade shows three bands of twist core patterned steel running the length of the blade. This pattern, created from a twisted rod incorporated into the blade for each band, repeats itself along each band with slight changes as curved patterns merge into a zone where the appearance is more that of diagonal lines.

Caucasian *kindjal* (or Persian *qama* or *quaddara)*, 18th to 19th century. Like the *yataghan* blade above, it has a central portion made of patterned steel with four bands into which deep fullers have been cut.

A European sword of the mid to late Viking Age, mid 10th to early 11th century, bearing a variant of the +ULFBERTH+ inscription on one face of the forte and a geometric pattern on the opposite face. The inlay is composed of twisted rods made from stacked steels of varying composition likely forged into grooves in the face of the blade and then dressed flat. Though contemporary with the Vikings, the brazil nut pommel suggests mounting nearer the origin of the blade, speculated to have been in what is now Germany. The steel surrounding the inscription has been brightened by polishing to increase contrast.

Iron Inlaid Inscriptions and Symbols

Twisted, stacked rods were not just employed side by side at the center of a blade, but could also be employed to form symbols and inscriptions. Modern recreations of this feature usually begin with channels being chiseled into a nearly complete blade where the inlay is to be set, followed by forging of the twisted rod that comprises the inlay into the channel. Such inlays may be seen laid over a background of pattern-welding, however, this technique is best known for having survived to be incorporated into somewhat later blades of homogenous steel. Perhaps the most famous application is that of the +ULFBERHT+ inscriptions (usually opposite a geometric lattice on the opposite face). Many authors have interpreted this as a Frankish name and the early appearance of a 'trademark.' If so, the mark was widely counterfeited, based upon numerous variations in spelling. One group, inscribed +ULFBERH+T, is associated with superior high carbon steel and it has been hypothesized that this steel was imported from Asia via Viking Age trade routes.

Details of an Indian chevron patterned *talwar* , likely 19th or 20th century. Clearly made for show, but fully serviceable if the welds are well made.

Indian Chevron Patterned Blades

Perhaps the most unlikely of any multicomponent blade construction is the chevron patterned Indian blade. The bold chevrons are full-thickness alternations of material, with weld boundaries between the areas of brighter patterned metal and darker non-patterned metal. The pattern seen in the brighter areas is developed from a blade surface very nearly parallel to the planes of layered contrasting alloys, with minor variations in forging of less than a millimeter causing a bold random surface pattern. Such a construction would predispose to failure if any of the many welds between chevrons are defective. Two swords of similar construction are illustrated in Figel (1991), p. 104 - 107 and a dagger of similar construction is illustrated in Sachse (1994), p. 98.

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