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## ON THE MANUFACTURE OF IRON INLAYS IN SWORD BLADES: AN EXPERIMENTAL STUDY

### Abstract

This article deals with the manufacturing techniques of iron inlays on sword blades during the Late Iron Age, circa AD 750–1200. These inlays were welded on the surface of the blade from pattern-welded material or from plain iron or steel rods. This article presents the results of a series of experiments aimed to find out the manufacturing techniques of iron inlays. These experiments were conducted according to the principles of experimental archaeology, and they consisted of the forging of thirteen blades with inlays. Experiments were based on artefact studies concentrating on materials and techniques, which both showed some variations in archaeological find material. As a result, the most probable technique for making iron inlays is presented, together with alternative techniques producing almost similar results.

Keywords: swords, Viking Age, blacksmithing, experimental archaeology, iron inlay

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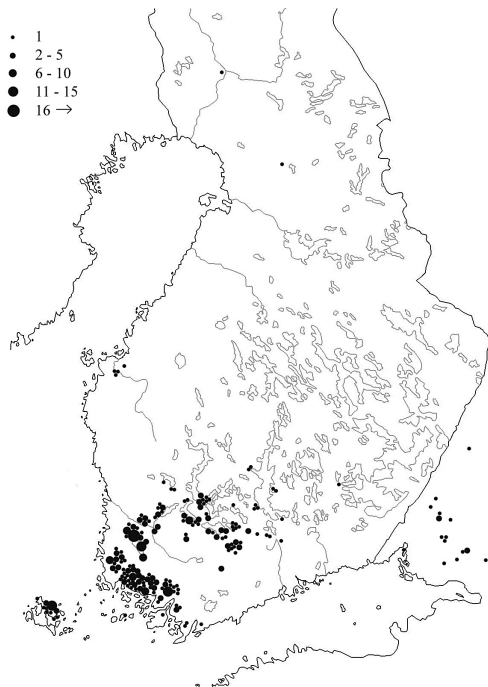
### INTRODUCTION

#### *Prehistoric background*

Iron inlays are a common feature in sword blades during the Late Iron Age. According to the current studies, the first inlays appear already at the end of the Merovingian period before the year AD 800, and they continue to be used throughout the Viking Age (ca. AD 800–1050 in Finnish chronology) and onwards to the 1200s (e.g., Geibig 1991: 155). In the technical point of view these inlays were made by sinking metallic letters and patterns into a different base metal, that is, the blade. Inscriptions and motifs are by no means carved into the blades, but made from separate, contrasting metal.

The study of iron inlaid swords in Finland is currently being carried out by the author. The observations presented in this article concerning the technical features and the materials of inlays are based on the Finnish material, in addition to previously published information and analyses.

When writing this article, a total of 82 inlaid blades were documented, and most of these were previously unknown to carry inlays. No systematic research has taken place to reveal all inlaid blades among Finnish finds, so the task is vast. In Finland there are over 350 swords dating to the Late Iron Age, including the Viking and Crusade periods (Fig. 1). 316 of these swords are dated to the Viking Age (Räty 1983: 10; Lehtosalo-Hilander 1985: 6–7). The above-mentioned figures are estimations which do not include the finds from the last two decades, so the number of Late Iron Age swords is probably even greater. Moreover, blades without hilts and smaller fragments of blades are hard to date, so they are not included in these estimates. The majority of these Viking Age swords have been found in cremation cemeteries, while some are stray finds not connected to a cemetery or a burial. During the Crusade period (ca. AD 1050–1150/1300 in Finnish chronology), swords were placed in inhumation graves, from which they were recovered. Still some stray finds occur,



*Fig. 1. The distribution of Viking and Crusade period swords in Finland, including the area of ceded Karelia, based on classifiable and thus datable swords and hilt parts. The distribution is fairly similar to the distribution of contemporary cremation and inhumation cemeteries, especially in southwestern Finland. Map: Mikko Moilanen.*

and they are not always clearly associated with a burial.

Traditionally the contents of iron inlays are interpreted as names of blacksmiths or smithies, ULFBERHT and INGELRII being the most common ones during the Viking Age. At the end of the Viking Age phrases and abbreviations related to Christianity begin to appear; especially IN NOMINE DOMINI ('in the name of God') is repeatedly used in various forms. In addition to these clearly readable inscriptions, a great variety of different symbolical motives, for example circles, lattices and omegas, are observable. The meaning of these patterns is unknown, but perhaps they too are marks of the smithies (e.g., Lorange 1889: 12–4; Kirpichnikov & Stalsberg 1993: 37). Also misspelled inscriptions appear, and they are often suggested to be copies of some original inscribed blades and made by

illiterate blacksmiths (e.g., Vilkuna 1975: 78; Kirpichnikov & Stalsberg 1998: 509). Then again, the motives are not obliged to have a purpose other than make the sword look better or more expensive.

A distinctive feature of these inlays, especially those of the Viking period, is that the majority of them are pattern-welded (Fig. 2). In a technical sense, pattern-welding means that two different kinds of iron or steel are welded together and then manipulated to create a desired pattern. The technique has both a decorative function (e.g., Williams 1977: 75; Tylecote & Gilmour 1986: 1–2) and a technological function to increase the toughness of the blade (e.g., Tylecote 1976: 66; Andresen 1994: 198). For these reasons pattern-welding was used to compose whole sword blades especially during the Migration and Merovingian periods (ca. AD 400–800) and even during the early Viking Age. Slowly, due to the production of better steel, pattern-welding was no more used to construct whole blades, but instead it was used for the inlays.

Perhaps pattern-welding, in one form or another, was seen as a sign of quality or high price (e.g., Tylecote & Gilmour 1986: 2), and therefore its tradition was continued in the form of inlays. After all, pattern-welding can be seen as a kind of demonstration of the skills of the blacksmith, who could create a desired pattern on the finished blade. It is quite obvious that not all blacksmiths could master pattern-welding, as they still can't today. Besides a proof of blacksmith's skills, pattern-welding was also more costly since it required a lot more effort and time than more simple solutions. Still, according to metallographic analyses conducted on pattern-welded blades (see e.g., Smith 1957; Thålin 1967; Thomsen 1971; Anteins 1973; Tylecote & Gilmour 1986; Edge & Williams 2003; Thålin-Bergman & Arrhenius 2005), it can be claimed that pattern-welding was not necessarily connected to high quality, but even more to aesthetics. According to these above-mentioned analyses, many pattern-welded blades from the Late Iron Age were of so poor quality that they would not have been very functional and durable in combat situations.

The inlays are usually fitted into the concave fuller running in the middle of the blade. Typically inlays are attached to the upper portion of the blade, that is, near the hilt (Fig.

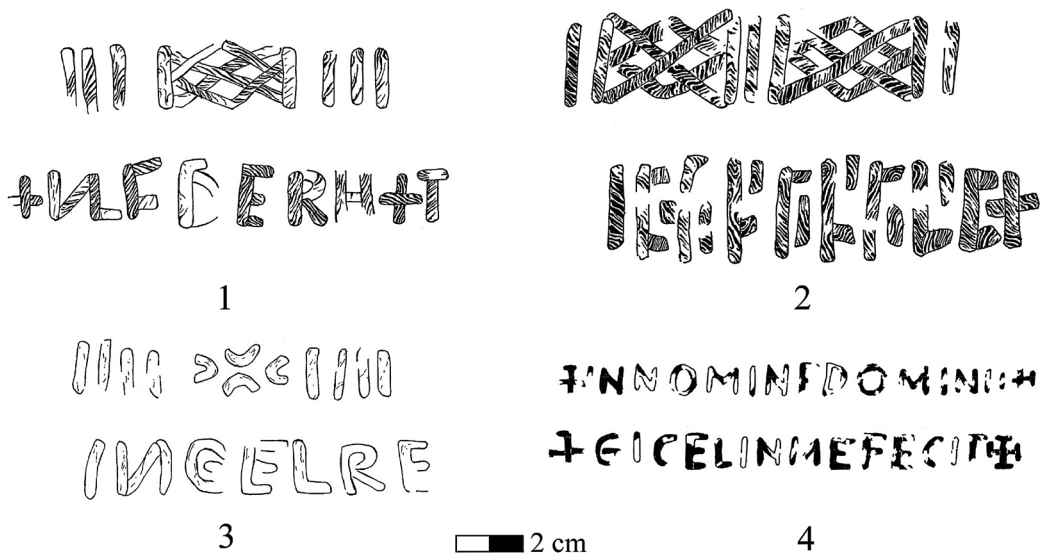


Fig. 2. Inlays made from different materials: large pattern-welded inlays (1. NM 9164:3, Eura, Pappilanmäki, and 2. NM 13419:2, Maaria, Taskula), large iron inlays (3. NM 2508:124, Pudasjärvi, Kurjenkoski), and small steel inlays (4. NM 3631:1, Rovaniemi, Marikkovaara). Drawings: Mikko Moilanen.

3), but there are examples of blades inlaid in their whole length too. At the very end of the Viking period the material of the inlays changes to non-pattern welded, simple iron or steel rod, and the size of the inlays becomes much smaller due to the decreased width of the fuller. Crusade period inlays are normally only half of the size compared to those common in the Viking Age. In average, the height of the inlaid letters is circa two centimetres during the Viking period, while later their height decreases to one centimetre, as well as the width of the fuller too. This resizing of inlays is then connected to the overall evolution of the blade shape. It must be noted that the transition from pattern-welded to inlayed blades did not take place suddenly. Numerous blades with both pattern-welded mid-section and inlays on top of it are also known. Correspondingly, some Viking Age blades with non-patterned inlays, and some Crusade period swords with small, pattern-welded inlays are also known. Traditionally pattern-welding is seen as a sign of a Frankish bladesmith, and therefore it has been assumed that inlaid blades too were forged in Frankish smithies. These points of view are starting to crumble due to the clarification of the

pattern-welding technique itself, and due to the great amount of pattern-welded artefacts all over Iron Age Europe (see e.g., Kirpichnikov 1970; Thålin-Bergman 1983; Stalsberg 1989; 1994; Martens 2004). Inlays, however, have in many cases still been considered of a Frankish origin, which is probably caused by the fact that their manufacturing techniques have not been clarified in practice. Many theories, some of which will be presented later in this article, exist, but no one actually knows how pattern-welded inlays were practically produced.

#### **Aim of this article**

This article presents briefly the results of a series of experiments aimed to finding out the possible techniques of manufacture of iron inlays. The experiments started already in 2003 when two first inscribed blades were made for my Bachelor's thesis. The experiments were continued for my Master's thesis (Moilanen 2006a), when five more blades were forged. After the completion of my master's thesis, six more inscribed blades were manufactured to conclude the series of experiments. All the

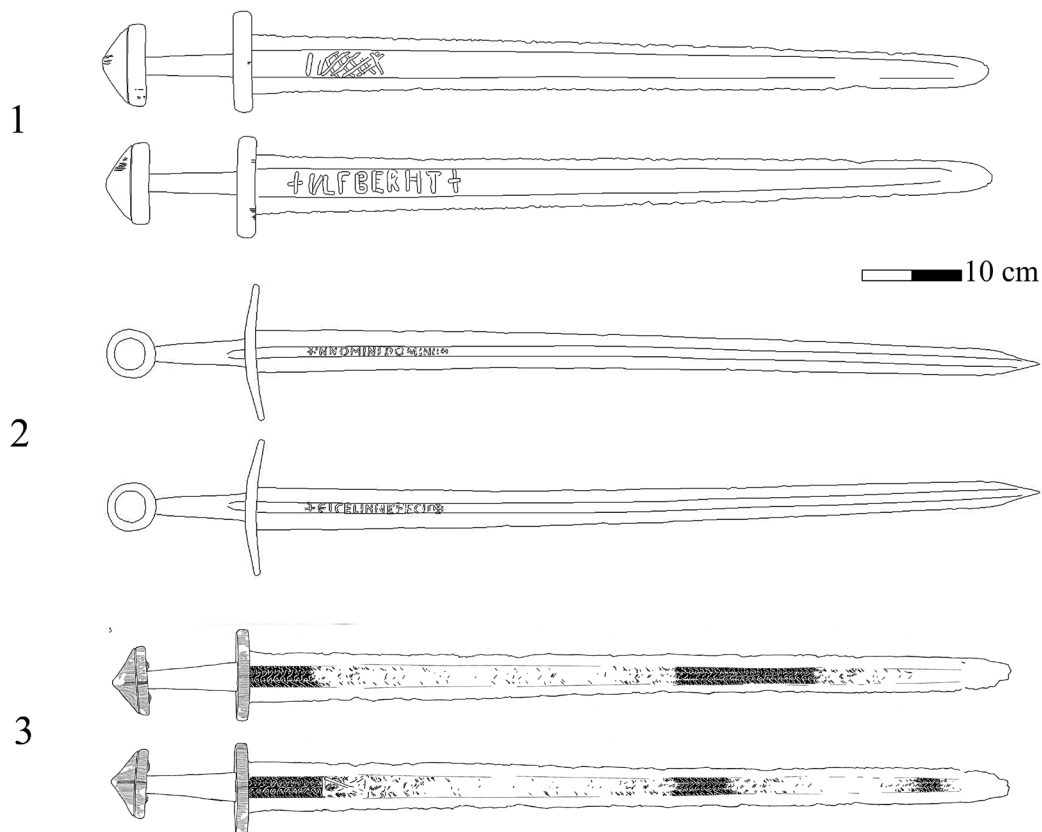


Fig. 3. Different kinds of inlaid blades: 1. NM 18402:1 (Hämeenlinna, Peltorinne) with pattern-welded inlays, 2. NM 3631:1 (Rovaniemi, Marikkovaara) with steel inlays, and 3. NM 293 (Saltvik, Bertby) with iron lattice on one side of a pattern-welded blade. Drawings: Mikko Moilanen.

forging experiments were conducted according to the principles of experimental archaeology to make the results as authentic and as applicable as possible. I conducted the experiments myself due to my blacksmithing background. I have also discussed the theoretical perspectives of iron-working experiments in one of my previous articles (Moilanen 2007b), so I will not present them in detail here.

I have published some articles about the experiments, most of them in popular forums (Moilanen 2006b; 2006c; 2007a; 2007b). None of these contain the final results but only the results of experiments conducted at that point. It should be stressed that my viewpoints regarding the topics of these articles have changed since the series of experiments was concluded.

My series of experiments is not entirely published in this article, but only the results.

More detailed descriptions of all the experiments will be published in my future doctoral thesis, where experiments are used in the interpretation of details evident in archaeological finds. Moreover, the descriptions and documentation of all the experiments are far too extensive to be handled in a single article. The purpose of this article, then, is to present the results of the experiments, that is, an explanation of how iron inlays could have been manufactured.

One reason for this publication is the growing interest in the manufacturing techniques of iron inlays. Besides archaeologists, also craftsmen are becoming very interested in these kinds of inlays, for they want to replicate them in their commercial products. Some blacksmiths or bladesmiths, to be more precise, have already produced pattern-welded inlays on some custom swords they have sold. My intention

then is to share my knowledge gained through my own experiments and observations from archaeological material.

## BACKGROUND OF THE EXPERIMENTS

### *Material and technical studies*

The aim of the experiments was to reconstruct a technology, which can be seen as a combination of materials, tools and techniques. To guarantee reliable results, all these should be studied and replicated in the experiments to some degree. Materials and techniques can be observed from archaeological sword finds. In addition, archaeological finds of blacksmithing tools should be considered in order to use the same kinds of tools in the experiments.

The material and technical studies can be divided into two categories: materials and manufacturing techniques of inlays and materials and construction techniques of blades themselves. In the view of the experiments, the materials used should be as close to originals as possible. However, it is not necessary to construct the blades similarly; only the material of the surface of the blade should correspond, because the inlays are attached only on the surface.

Both the materials and construction techniques of blades vary a lot. According to analyses conducted in previous research (e.g., Petersen 1919: 209; Jankuhn 1951: 225; Anteins 1973: 40, 53; Williams 1977: 81–4; Törnblom 1982: 25; Tylecote & Gilmour 1986: 218–20, 224–7, 234–6; Edge & Williams 2003: 194; Thålin-Bergman & Arrhenius 2005: 100–101), the carbon contents of inlayed blades vary between 0 and 1.2 per cent. The more carbon steel has the tougher and harder it is, and the less temperature is needed to weld it.

Similarly, the methods of construction also show great variation. The traditional assumption is that all inscribed blades were made of homogeneous steel (e.g., Oakeshott 1960: 43), but in reality, all cross-sectionally analysed inlayed blades were welded from multiple pieces, the structure being lengthwise laminated (see Leppäaho 1964: 8–9; Anteins 1973: 48, 53; Williams 1977: 81–4; Törnblom 1982: 25; Tylecote & Gilmour 1986: 218–20, 224–7, 234–6; Edge & Williams 2003: 194; Thålin-Bergman

& Arrhenius 2005: 100–101). Normally the parts with lower carbon content are found near the core, while the higher carbon parts are used to build the surface and the edges of the blade. This creates a hard blade with added flexibility from the iron core. The above-mentioned analyses consist of both cross-sectional cuts and chemical analyses. In cross-section analysis, the completely or half-way cut cross-section of the blade is polished and etched to show the structure of the blade and relative carbon contents of the materials. In chemical analyses the elements present in the iron or steel are measured more precisely.

The inlays are traditionally said to be made of iron, while the blades are steel (e.g. Oakeshott 1960: 143–4; Tylecote & Gilmour 1986: 248; Tylecote 1987: 276). Again, the materials are numerous. Commonly the inlays are pattern-welded, while plain iron and steel inlays also occur. The term ‘iron’ here means that the carbon content of the inlays is lower than that of the blade surface. The ‘steel’ on the other hand means that the carbon content of inlayed rods is greater than that of the blade. In a ready, polished and etched blade, iron inlays will show brighter and steel inlays darker than the blade. Pattern-welded inlays are constructed of two contrasting steels, which have either different carbon contents or different phosphorus contents. When etched with some acid, phosphorus-rich iron will remain bright in colour (e.g., Anteins 1973: 27; Godfrey et al. 2003: 191).

Many theories do exist about attaching iron inlays. These theories have rarely been applied into practice. One hypothesis is that short lengths of wire were hammered cold into cut or punched grooves (e.g., Bruhn Hoffmeyer 1954: 110; Tylecote & Gilmour 1986: 276). Still the majority of researchers are of the opinion that inlays were welded into their places. Some think that there were pre-cut grooves into which inlays were placed and welded (e.g., Oakeshott 1960: 143–4; Ypey 1980: 203; East et al. 1985: 6). It has also been suggested that the diagonal lines on corroded inlays are punch-marks from a chisel-like tool used to drive the inlays into their position (East et al. 1985: 6). In my opinion, these streaks are more likely caused by corrosion, when the higher-carbon layers of pattern-welded rod have corroded deeper than the iron (i.e. lower-carbon)

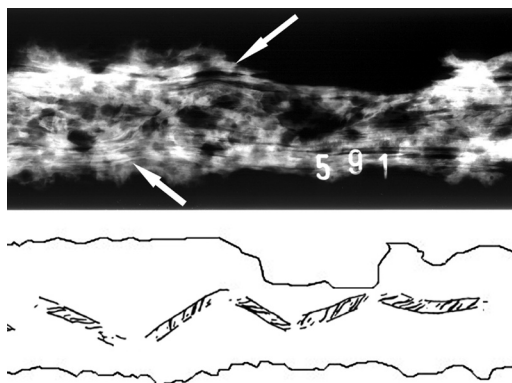


Fig. 4. Bent blade structure around pattern-welded inlays. Above: radiograph of a sword from Eura, Kauttua (NM 5334:1), showing its striated blade structure being bent towards the blade edges (arrows). Below: inlays of the same sword drawn. Radiograph: NM/Conservation department, radiograph archive. Drawing: Mikko Moilanen.

layers. On the other hand, some scholars have proposed that no grooves were made and the inlaid wire was welded straight on the surface of the blade (e.g., Andresen 1993; Kirpichnikov & Stalsberg 1998: 507). It must be noted that these theories are not always based on artefact studies, but are mere speculation.

Two published experiments exist on the matter, both made by Norwegian blacksmiths. The first was made by Kasper Andresen (1993), and the second one was conducted by Hans-Johnny Hansen (2007). In Andresen's experiment only few steel letters were welded on iron plate, but I still used his technique as the basis of my experiments. After all, Andresen based his technique on examination of actual finds. Hansen, on the other hand, managed to create a complete ULFBERHT-blade with inlays on both sides of the blade, as is the case in archaeological finds too. It must be noted that Hansen's results were published when my own experiments on pattern-welded inlays were almost complete, so both Hansen's and my results were achieved independently from each other.

The finds themselves can give hints about the techniques. Mostly the traces are visible as fibrous blade structure revealed by corrosion and bent under and around the inlays (see e.g., Maryon 1950: 177; Andresen 1993: 38) (Figs.

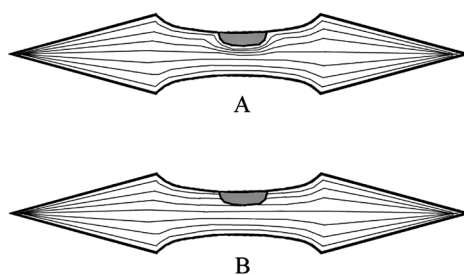


Fig. 5. A schematic cross-section of an inlaid sword blade showing the blade structure bending below the inlay (A); and a blade in which an inlay was sunk and welded into a cut or chiselled groove (B). Drawings: Mikko Moilanen.

4 and 5). This wavy structure that is observable in iron artefacts is produced by the process of folding and welding of iron to remove impurities and to increase toughness (e.g., Ypey 1980: 193). The bent structure in inlaid blades indicates that no grooves were carved for the inlays, and that serious hammering has taken place. This phenomenon can best be seen in blades, which have inlays over pattern-welded mid-section.

Some cross-sectional analyses of inlays have also been made (Leppäaho 1964: 9; Anteins 1973: 43; Törnblom 1982: 25; Thälin-Bergman & Arrhenius 2005: 100–101). According to these analyses, inlays were attached by forge-welding, and they have sunk from half to 1.5 millimetres. It must be noted here that the depth of the inlay in its present state is affected by the corrosion of the blade, and thus the inlays may have been originally deeper than these above-mentioned measurements show. What comes to forge-welding as the technique of attachment, it has apparently been stated on the grounds of the outlook of the cross-section. Without forge-welding, there should be a clear visible seam underneath the inlay, instead that the inlay seems to fuse into the blade. Moreover, if these analysed inlays were attached without forge-welding, they should look wider at the bottom when inspected at their cross-section. The only way to make an inlaid wire to hold in its place without welding is to carve a groove, which is wider at its bottom.

In addition to these details, there are other indications of possible alternative inlaying

techniques. Some letters appear to have been assembled of very small and square-cornered bits of rods, thus possibly cold inlaid into pre-made grooves before the welding operation. Some inscriptions, on the other hand, appear to be welded on a very shallow depth, indicating that the inlays were welded straight on the surface of the blade without sinking them in. Examples of these are presented later in this article, as well as details of their possible ways of production.

It must also be noted that no literary sources describe the manufacture of iron inlays, nor has the process been pictured. The only mention about inlaying figures and motives on blades comes from the presumably 12<sup>th</sup> century treatise on painting, glassmaking and metalwork by Theophilus Presbyter. According to this treatise, figures were hammered into cut grooves with a small hammer (Theophilus Presbyter 12<sup>th</sup> c. [1979]: 186). This technique, however, describes the inlaying process of non-ferrous wires.

### ***The practical work***

After material and technical studies, the practical part of the experiments was planned and executed. This included the selection of tools, which were quite the same in form and function as those used during the Late Iron Age. Archaeological finds were used as examples for these tools. After all, blacksmithing tools have remained quite standard since the Roman times (e.g., Gaitzsch 1980: 256). The experiments were conducted with as few and simple tools as possible to observe, what kinds of tools are actually needed in the making of an inscribed sword blade.

Also the materials for blades and inlays were selected according to the finds. This, of course, allowed a great range of materials. In general, different carbon steels were used as blades, and almost pure iron (less than 0.1 % carbon) was used in the laminations of pattern-welded inlays together with carbon steels. At first, the steels were old car springs, which contained 0.5–0.8 % carbon and small amounts of other alloying elements, such as manganese, silicon, sulphur and phosphorus. During the experiments this steel proved out to be too tough, so old iron from the 18th century was eventually used. The composition of this iron was not analysed, but it contained enough carbon to be quench-hardened,

and most likely did not contain as much alloying elements as industrial steel.

The experiments began with the making of a trial piece to find out one possible technique for attaching one inlaid mark. Thereafter the technique was applied in making complete inscriptions on a blade. The series of experiments was not actually planned, but additional experiments were made according to the results of the previous experiment, and of course those questions, which arose during it. In principle, the same technique to attach one inlay was tried in blades with different phase of manufacture, unless some alternatives seemed obviously impossible. The phase of manufacture here means the phase of forging of the blade. General phases tested in the experiments were a blade blank, a blade with fuller forged partially or completely, and a blade with both fullers and bevels forged. When a new technique for making an inlay was introduced, it was first tested on a new trial piece to avoid spoiling a complete blade.

In all, thirteen blades with inlays on both sides of the blade were forged. The last two of these were attempts to produce smaller iron or steel inlay, while all other blades had large pattern-welded inlays. The two smaller inlaid motives were made to find out if the most plausible techniques for making larger inlays would work also for smaller ones. Again it must be stressed that the descriptions of these experiments will be published in my future doctoral thesis. Here are presented only the results of the whole experimental series, without interfering into specific, single experiments.

### **THE RESULTS: HOW IRON INLAYS WERE PRODUCED**

#### ***The optimal technique***

To begin with, first the rods for the inlays were made. If inlays were to be done from plain iron or steel rod, it just had to be forged round. The diameter of the inlaid rod should be approximately little less than the finished inlay should be. Normally large inlays, including the pattern-welded ones, were made from a rod with a diameter between two and four millimetres. Smaller inlays evident in Crusade period blades were about 1–1.5 millimetres in diameter before they were attached into blades. Once a round



Fig. 6. The making of a pattern-welded pack: 1. a pack made from alternating sheets of iron and steel, bound together with iron wire, 2. forge-welding the pack by hammering, 3. completely welded and solid pack. Photographs: Mikko Moilanen.

rod was made, it was shaped to form letters and marks. This could be done with small pliers or by forging with a little hammer. The forming was easiest while the rod was heated in a forge. The forging temperatures ranged between ca. 800 and 1000 °C. Temperatures were estimated by the colour of the heated steel.

In the case of pattern-welded inlays, the making of the rod was a bit more laborious. First, a pack of alternating layers of iron and steel was made (Fig. 6). The layers of ‘iron’ and ‘steel’ mean simply that two materials with different carbon contents (or phosphorus contents) were used. In the experiments, variations of carbon content were used to create the contrast, because phosphorus-rich iron could not be obtained at the time of the experiments. The pack normally consists of seven or nine layers, although greater layer counts are observable too in the archaeological material. The pack was then forge-welded solid in a temperature of 1200–1400 °C. Then the solid pack was hammered flat and narrow strips were sawn or cut (Fig. 7). These strips were then twisted around their own axis, then hammered round and shaped into letters and marks. Optionally the pack could be lengthened to a thin rod by hammering, but this is considerably harder and more laborious.

In practice, *forge-welding* is a procedure where two parts of iron or steel are joined together by hammering them in a high temperature. For this reason the technique has sometimes been called *hammer-welding*. The principle is that the parts to be joined are heated to such a temperature, where the surface of these parts is liquid but they still retain their form. Typically this temperature, the welding temperature, is somewhere between 1200–1400 °C, depending on the composition of the materials. The higher the carbon content the lower the welding temperature. When the temperature is reached, the parts are taken from the forge and quickly hammered against each other on top of an anvil, so the liquid faces will melt together. In this kind of welding, a so-called flux is needed. A welding flux is a substance, which melts around the parts to be welded, creating an airtight seal and thus preventing the oxidation of welded pieces. During the Iron Age, fine quartz sand was probably used (Andresen 1994: 197). If iron is oxidized, it will not weld because thin, oxidized layers of iron are formed in the welding seams.

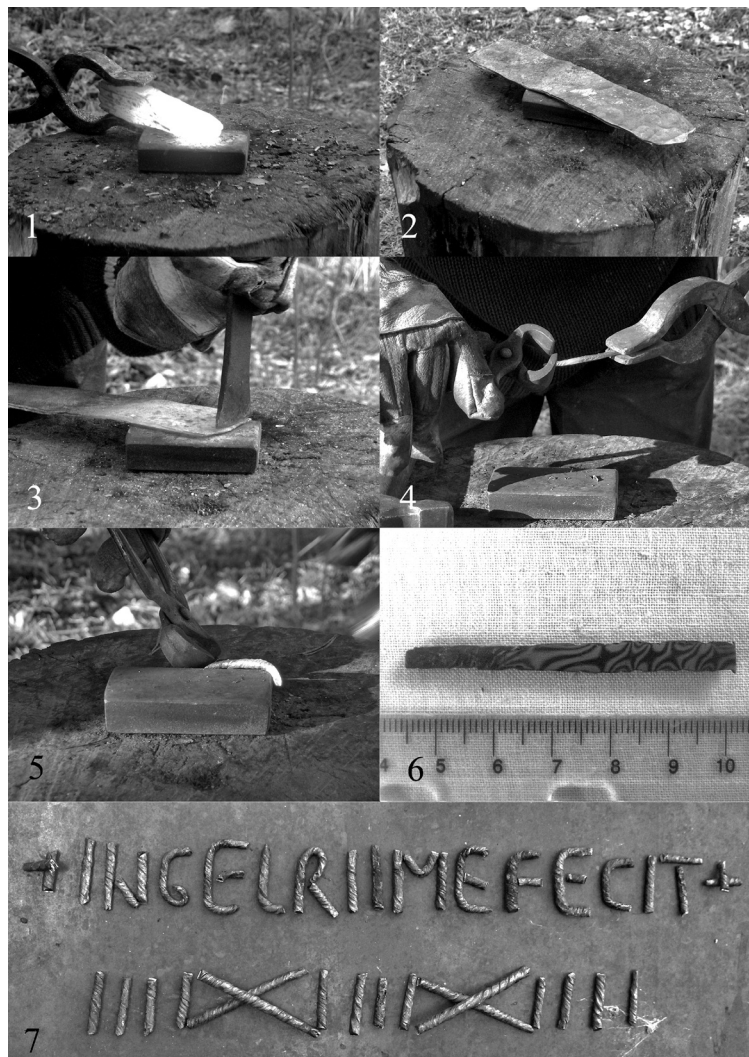
After the inlays, the making of the blade took place. However, the blade was left as a blank. This means that the basic shape of the blade was forged, but not the bevels or the fuller. The blank should also be about two millimetres thicker than the ready blade, at least in the inscribed



portion. The inlays were attached to this blank, one by one. First inlays of one side of the blade were attached. One by one, the inlays were first hammered cold into the hot blade (Fig. 8). The place of the inlay was heated to a yellow heat, after which the inlay was placed cold on top of the heated blade. Quickly, the inlay was hammered so that it sunk all the way into the blade. After all inlays on one side of the blade were sunk in this manner, they were welded in a welding temperature with only three or four heats. This means that multiple letters were welded with only one heat in the forge. Then the inlays of the other side of the blade were sunk and welded in the same manner. Finally the blade was forged to its form; also the fullers were forged in order

to avoid grinding the inlays away later (Fig. 9). No additional tools were required. The forging could have been done with only hammers and a small anvil with perhaps one rounded edge.

In theory, the inlays of one side of the blade could all have been sunk with only one heat. This could be achieved by, for example, attaching all inlays of one side of blade into an iron bar, by the help of flux or some other somewhat heat-resistant glue-like substance. This bar would then be placed on top of a heated blade, and then hammered quickly and forcefully to make all inlays sink into the blade. However, this has not been put into practice. This method would certainly speed up the process, and make the inlays sink aligned and in even depth.



*Fig. 7. Making of rods for inlays from a pattern-welded pack: 1. flattening of pack by hammering, 2. pack is flattened to a thin sheet, 3. cutting a strip with a chisel, 4. twisting the strip with tongs, 5. forming the letters and marks by hot-forging, 6. a pattern-welded rod, which is nearly halfway ground, polished and etched, showing its patterns, 7. an example of text and inlays made from twisted pattern-welded rod. Photographs: Mikko Moilanen.*

After forging, the blade was heat-treated (i.e. hardened) by plunging it in a red heat into warm water. It must be noted that the heat-treating methods have varied greatly during the Late Iron Age, and sometimes a blade was not hardened at all for some reason (see e.g., Tylecote & Gilmour 1986). After hardening, the blade was ground, sharpened and polished. The inlays were etched with some mild acid to create a contrast between them and the blade, and to bring the patterns of the inlaid rods visible. During the experiments, vinegar was used in the etching procedures. In antiquity the etching could have been done with fruit juice (Smith 1957: 200; Andresen 1994: 198; Edge & Williams 2003: 203), urine (Liestøl 1951: 88; Arrhenius 1989: 100), or corrosive mineral (Smith 1957: 200).

The above-described method is the easiest and safest way to attach the inlays, whether they were large pattern-welded ones, or smaller iron or steel inlays. The depth of the inlays was over one millimetre, as in analysed finds too. Similarities can be found in patterns of the inlays, and imperfect welding seams visible in both the finds and the results of the experiments (Fig. 10). The presence of these partially failed welding seams is the result of the forging of the blade in its shape. While forging the fuller and the bevels, the blade lengthens and the welding seams stretch, sometimes even break, if there are impurities trapped in the welding seams.

In the case of small, non-patterned inlays found in swords typical in the Crusade period,

experiments have shown that they could have had very small grooves, in which the inlays were placed before they were hammered into the blade. This theory, already presented by Herbert Maryon (1950: 177–8), is based on the observation that small inlays tend to heat too much if they are not hammered into the blade in two or three seconds after their first touch with the hot blade. Without small guiding grooves, the inlays cannot be adjusted as straight and neat as possible before they must be hammered. The small steel inlays in Fig. 10 were welded without guiding grooves, which led the inlays to be tilted and misaligned. Of course, small guiding grooves may have been carved in Viking Age blades with larger inlays too.

Here something must be mentioned concerning the critique of the experiments, which was mainly aimed at the materials of the blades. In only four last experiments the steel used for the blade was not modern alloyed steel. Industrial steel is a bit tougher due to its alloying elements, and this was noticed to have a crucial meaning in the experiments. More primitive steel with only very small amounts of alloying elements was found to be considerably softer and easier to work, and it also made the attaching of inlays easier and also made possible to formulate the optimal method described above. As a further note, the majority of the inlays created in the experiments were incomplete, and the blades were not at all satisfactory.



*Fig. 8. Attaching of inlays with the optimal method: 1. cold rod placed on the surface of the hot blade blank, 2. rod is hammered to make it sink completely into the blade, 3. after all inlays on one side are sunk, they are welded in a high temperature, 4. detail of welded inlays on a blade blank. Photographs: Mikko Moilanen.*

*Fig. 9. Forging a fuller on an inlaid sword blade.  
Photograph: Ulla Moilanen.*



### **Alternative ways**

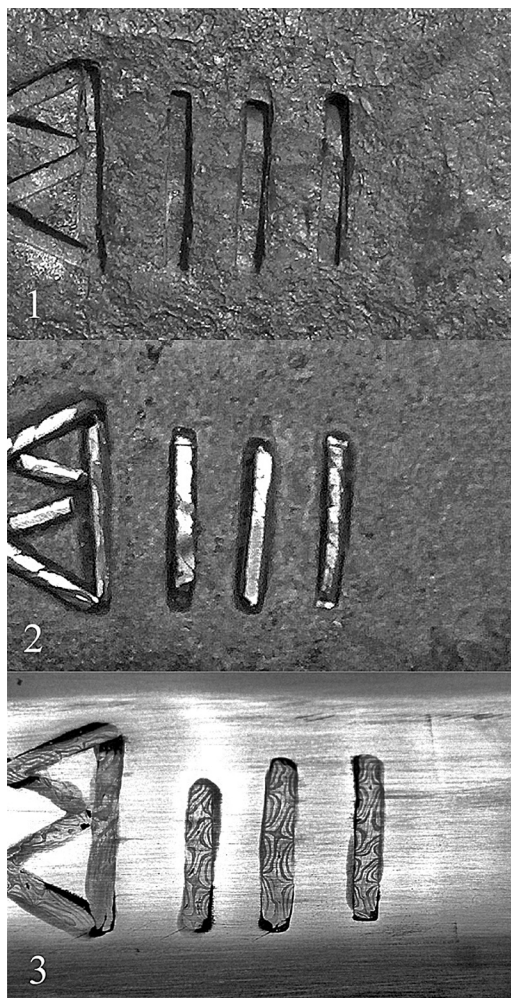
The series of experiments helped to list different possible options of how and in what phase of manufacture the inlays could be attached. It is certain that a ready, polished blade could not be inlaid with ferrous material in any manner. The forge-welding of the inlays would oxidize the blade so much that it would end up being too thin in its inlaid part. In addition, the whole blade should be thinned to keep it well-balanced. Of course, even iron inlays could be sunk into grooves by hammering them cold, but this is not supported by archaeological finds.

Since there are two factors affecting the attaching of the inlays – the technique itself and the manufacturing phase of the blade – there are

many alternatives. Single inlays may be welded into pre-cut grooves. This technique was not even experimented, because it was so obvious, and some commercial bladesmiths are producing inlays with this particular method. Because any of the studied finds did not straightforwardly support this technique, the grooves could also be struck with punches, creating a bent blade structure (Fig. 11). The carving of grooves is, however, a likely way to get the job done. With both these techniques it is possible to sink the inlays as deep as the finds indicate. A sword blade fragment from Sääksmäki, Rapola (NM 2767) had inlaid letters made from small pieces of rods, and the outlook of the letters suggests that they were sunk into some pre-made grooves (Fig. 12). The inlaid rods were pattern-welded,



*Fig. 10. Inlays on ready sword blades: 1. large pattern-welded inlays, 2. smaller steel inlays.  
Photographs: Mikko Moilanen.*



*Fig. 11. Inlaying in punched grooves: 1. punched grooves on a ready forged blade, 2. pattern-welded rods placed in the grooves, 3. ready, polished and etched inlays. Photographs: Mikko Moilanen.*

but surprisingly the layers were made from the same material, the patterns being somewhat unnoticeable.

Andresen's (1993) technique in which an inlay is welded straight on the surface of the blade is also functional to some degree (Fig. 13). Inlays cannot be sunk as deep as is observable in analysed finds, but still visible inlays can be produced. This can be achieved by very careful work and with the help of great amounts of flux to prevent the oxidation of steel. The problem with Andresen's technique is that the inlays are not deep enough to prevent them from being

oxidized. This can be prevented to some degree by adding flux on top of the inlays after every heat in the forge. Still small parts of inlays can easily be lost during forging, grinding and polishing of the blade. Especially the first inlaid side of the blade will easily lose its inlays when welding motives on the opposite side of the blade. This phenomenon may have happened in the case of a sword blade from Tampere, Messukylä (NM 6066:1), which has fragments of a possible VLFBERH+T-inscription still visible (Fig. 12). The sword is rather well-preserved, but the majority of the inlays are gone. The blade has been very lightly mechanically cleansed during some previous research, but most likely the inlays were partially gone already when the blade was finished in antiquity.

It should be noted that Andresen's technique does not work well in the case of smaller iron or steel inlays. Due to their small size, they oxidize much easier, and they do not sink as much as bigger inlays. Either the optimal technique should be used, or then some deep grooves should be made beforehand for the inlays.

All above-mentioned different methods to attach an iron inlay can then be applied to blades in different phase of manufacture. The Andresen's technique can be used when the blade is still a blank, or has a semi-finished fuller, which is not yet in its intended depth. The most probable technique – hammering inlays deeper before welding – can produce good results when applied to a blade blank or a blade with semi-finished fuller. Pre-cut or punched grooves can in turn be made in a blank blade, a blade with semi-finished fuller, or even to a ready, forged blade, which has not been heat-treated, ground and polished, of course.

Another Norwegian blacksmith, Hans-Johnny Hansen published his experimental results concerning the making of an ULFBERHT-sword (Hansen 2007) after I had almost finished my experiments. We both arrived at the same conclusion about the optimal method. Hansen also hammered the inlays deeper into the blade before welding them. Still, Hansen was not completely satisfied with his results, because the inlays widened too much and they did not sink deep enough (Hansen 2007: 55). Maybe this is due to his choice of materials: if Hansen used modern steels, the technique will not work as well as with more authentic steels.

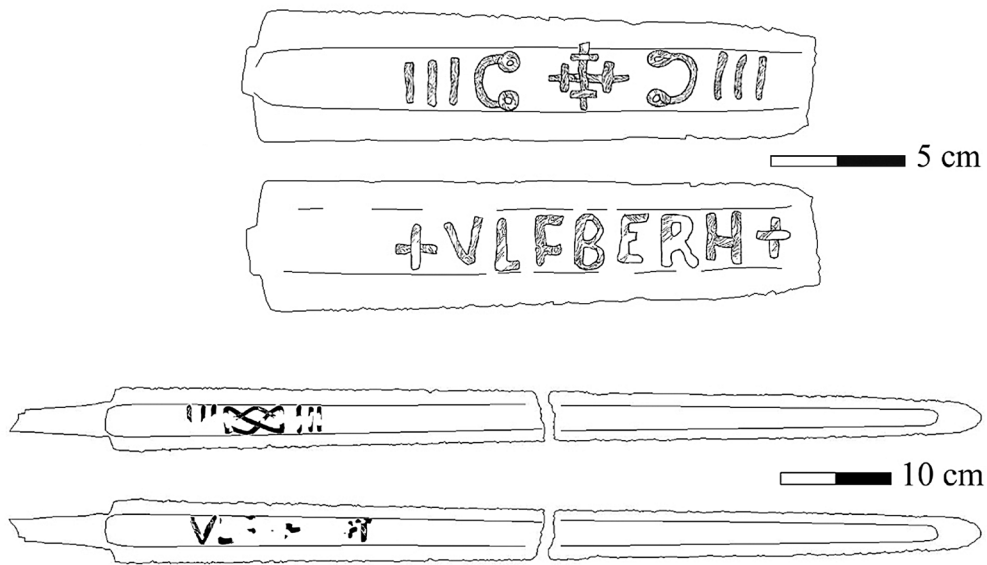


Fig. 12. Inlaid sword blades from Sääksmäki, Rapola (NM 2767) (above) and Tampere, Messukylä (NM 6066:1) (below). Drawings: Mikko Moilanen.

One further note should be made about the inlays. After and during inlaying iron, non-ferrous inlays came into use, possibly already before the 1100s. These non-ferrous inlays are not included in this article or the experiments, because their techniques of manufacture are clearly different from those used in iron inlays. Non-ferrous inlays do not need any forge-welding, but they can be hammered either hot or cold into pre-cut grooves on a ready blade. It can be claimed that when non-ferrous inlays started to replace iron ones, the techniques of inlaying iron into sword blades were practically forgotten. Still, the technique of pattern-welded inlays has been observed in some Polish knives from the 12th century (Thälin-Bergman & Arrhenius 2005: 33).

#### APPLICATION OF RESULTS

My hypothesis in my future doctoral thesis is that inscribed swords were produced locally aside from Frankish production. In other words, they were copied or independently produced outside Frankish areas, and possibly even in Scandinavia. It has been previously suggested

that due to the great amount and variation of pattern-welded and inlaid blades, they must have been produced locally. In my thesis I will analyse Finnish iron inlaid blades for their manufacturing techniques and materials to find out, if certain traditions stand out. Observations from the experiments are used to give advice, which details are to be studied and what they could mean. The different manufacturing techniques shown by the experiments can in turn be used to argue that iron inlays *were* copied, because of multiple techniques and their relatively easy execution.

As the experiments show, inlaying a sword blade is a relatively easy task, and in my opinion even an intermediate blacksmith could do this with only simple tools, including a small anvil, a hammer and tongs. It is also very likely that not one blacksmith was making the sword, but he had some helping hands. In this case the making of inlays becomes much faster and somewhat easier. If pattern-welding was mastered, the inlaid rods were also relatively easy to manufacture. It must be noted that numerous inlays have been made from non-pattern-welded material, even during the Viking Age. In these cases, most likely some

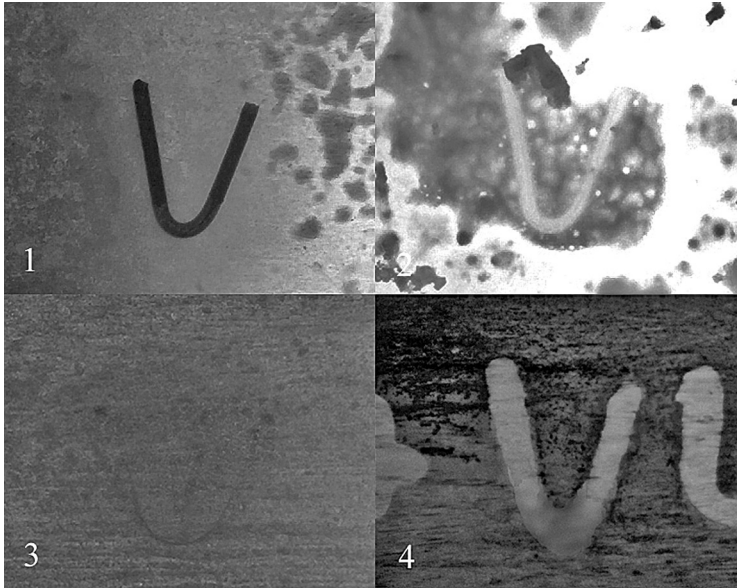


Fig. 13. Welding inlays straight on the surface of the blade, as Andresen (1993) suggested: 1. cold letter placed on top of a blade, 2. both the letter and the blade covered in flux and heated in a welding temperature, 3. letter V hammer-welded on the blade, 4. polished and etched iron inlay on a blade, which has etched darker than inlays. Photographs: Ulla Moilanen.

inlaying technique was deduced and applied; while pattern-welding itself was not necessarily mastered. What comes to pattern-welding, it was an old technique already during the Viking Age and it has been in use for centuries in Europe, so there must have been many blacksmiths mastering it. Pattern-welding could well have been learned by trial and error, as I did too.

The copying of inlaid motives and texts becomes more likely, when a diversity of techniques is shown. An Iron Age blacksmith may have seen an inlaid blade, and he wanted to make a similar one by using some of the techniques explained above. He may not have realised the easiest way, but used some other technique, which has worked as well. After all, not all blades can ever be analysed for their inlaying technique, and so it may be assumed that all working techniques were in use to some degree, depending on the maker.

It is also worth noticing that blades in different phase of manufacture may have been inlaid. Blade blanks as well as ready forged blades could have been marked with inlays, depending of course the fact that some suitable technique was known. This perception gives a reason to assume that even imported blades or blade blanks could have been inlaid outside the smithy that produced these blades or their blanks. In my opinion it is plausible that these iron-

inlaid blades could have been originally made in Frankish areas, but they were copied elsewhere. Plain, roughly forged blades or mere blade blanks could have been traded and then inlaid in commission by the purchaser. Furthermore, it is not impossible that both the blades and their inlays were made outside Frankish areas, even in Scandinavia.

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