11.3 Pattern Welding

11.3.1 Background to Pattern Welding

What is Pattern Welding?

Pattern welding is a special way of constructing a sword blade from a lot of iron / steel parts. Many different kinds of iron / steel parts are fire welded in such a way that a pleasing pattern can be observed on one or both sides of a blade. The pattern results because two *sufficiently different* kinds of iron / steel that intersect the surface reflect the light differently, in particular after some special polishing or etching.

You thus must use very special shapes of the parts to be welded to produce a *specific pattern*, and you must use quite different kinds of iron and steel to render the pattern *visible*. In other words: You must do structural and compositional piling, *and* you must do it in a way that produces the pattern you are after.

It is time now to look a bit closer at a few words that relate to the ways of making a sword. The first thing to note is that these words and their definitions had not been engraved by the finger of some God in tablets of stone or metal. They have not been handed down as unalterable eternal truth as claimed for some other stuff. There is, for example, no unique and undisputable definition of what "damask" or "damascening" means. It has meant different things to different people at different times. Come to think of it, even in the rare cases where writings in tablets of stone came down from high up, different people at different times interpreted these words differently. They even developed a strong tendency to kill everybody not agreeing with their interpretation even so one of those writings reads rather unambiguously "Thou shalt not kill".

What follows are therefore my personal definitions. I keep as closely as possible to the direct meaning of words, to established meanings in Materials Science, and to customary uses in the iron, steel and swords community. All of these terms I have used and defined before. Here goes:

- **Pattern welding**: *Fire welding* different kinds of iron / steel in such a way that a specific pattern occurs on the finished (and possibly etched) blade.
  Banging together (by fire welding) random pieces of iron / steel in a more or less random way will also produce a pattern on the finished blade. That pattern, however, is random and not intended. The resulting sword is not a pattern welded sword but a sword made by *piling*.
  Patterns will result if sufficiently different steels have been used and appear at the surface of the sword. Sufficiently different" in this context means that light is reflected differently, especially after some etching. It doesn't matter if the steels are mechanically or otherwise different; all that matters is that they are optically different. It is also important that both steels show at the surface. If one kind is completely enclosed by the other kind, for example in Japanese blades, you cannot possibly see it and there can be no pattern. I use the term "piling" for that.
  However, there are some (vague) reports that visible patterns can also result if identical or similar pieces of steel were badly welded. In this case large slag inclusions along the weld seams provide for the visible pattern. I have yet to see such a blade and will ignore them in what follows.
  Pattern welded swords belong to the group of *composite swords*.
  Pattern welded swords are often associated with the term "damascene", causing a lot of confusion.
- **Piling**: I have defined piling before, the link gets you there. Most generally it means that a big piece of iron / steel is made by fire welding smaller pieces. Piling can be done completely random or in very complex ways. Composite swords and pattern welded swords are always made by highly complex piling. Moreover, a smith could do complex piling in smart or stupid ways. Welding soft iron for the cutting edges-to-be to a hard core appears to be a rather stupid way of non-random piling, for example.
  Any pattern welded sword is a sword made by compositional and structural piling. But not every sword made by compositional and structural piling is a pattern welded sword; take a Japanese sword as example.
- **Damascene technology**. This term has been used and still is used for a considerable number of completely different things, most of which have nothing to do with the city of Damascus. More, the term was more than once introduced because of a misunderstanding or mistake. I try to avoid it as much as possible here.
  The special module gives all the details.

Special Module

Damascene Meanings

- **Damascene swords**. There is no such thing as a damascene sword, i.e. a peculiar type of sword that originated from the city of Damascus. A lot of people, however, do not know this and assume that a damascene sword is a extremely good sword that shows some pattern. The property of being very good is somehow associated with exhibiting a pattern. That leaves four possibilities

  1. The sword is a pattern welded sword. Indeed, these swords are often called "damascened", in particular in Germany, for unclear but faulty reasons.

2. The sword has been forged from a suitable crucible steel in such a way that a "watered silk" pattern appars on the blade. No piling and thus no pattern welding of any kind is involved. These *"wootz" blades*, as I like to call them, are sometimes called "**true damascene**", again for no good reason.
3. The sword was made by compositional piling but with no intention to produce a pattern. Many swords all over the world were made this way and none of them has anything to do with "damascening".
4. The sword has no intrinsic pattern whatsoever but somebody "painted", scratched, etched, or encrusted some pattern on the surface. Either to make it more beautiful or to fake a "damascus" pattern. Those fakes are sometimes called "false damascene".

So simply stop using any variant of the word "damascene" and you will do yourself and everybody else a big favor. I will avoid this term as far as possible.

Pattern welded swords are primarily objects of **art**. Pattern welding in its prime was *never* done because that technique makes for better swords. It was done because it makes for more *beautiful* swords.
There is only one problem with that statement:

Nobody today has ever seen an old pattern welded sword in its full glory.

Old pattern welded swords are at least 1000 years old. They were en vogue around 200 AD - 800 AD in Northern Europe, after 800 AD they slowly disappeared. Of course, pattern welding did not spring up with all its complexities over night. There was a continuous development from piling to complex pattern welding and early on some attempts at (simple) structural and compositional piling did produce better swords and (simple) patterns on the side. But going beyond that will only make your sword prettier, not better. I'll get to this in more detail later.
What is left of pattern welded swords typically looks like this:

Pattern welded swords from the Nydam treasure

Source: Photographed at Schleswig-Holstein Landesmuseum, Schleswig, Germany

These swords belong to the "**Nydam treasure**", all kinds of things unearthed from a Danish bog. In fact, Danish bogs yielded a lot of swords (more than 400) from around 100 AD - 500 AD, most of them Roman, and most of them pattern welded. That's why there are a lot of modules around those finds.
Discussing pattern welded swords means to look at a period of about 800 years in (Northern) Europe, give or take a a few centuries here and there. But all we have are the swords found in Danish bogs and a a few hundred, maybe close to a thousand, found in odd places or in graves all over the place but mostly in certain areas like South Germany. In other words: our knowledge from archaeological finds

Special Module

Bog Sacrifices

is rather patchy, in time as well as in space.

Not all that long ago almost nobody knew what a pattern welded sword in its prime looked like. However, in the last 20 years or so enterprising smiths have started to duplicate old blades. Foremost in Germany (and probably the world at large) was **Manfred Sachse**, whose replica of the "**sword from Ingersheim**" from 1992 in the Stuttgart museum more or less started me on this enterprise. Meanwhile quite a number of smiths make pattern welded swords. **Patrick Barta**, for example, specializes in making rather close replicas of some old swords, including making his own iron / steel in a bloomery.
Here are some of the patterns he realized:

Patterns in pattern-welded swords

Source: From the Internet pages of Patrick Barta; http://www.templ.net ; with friendly permission.

- It is impossible to convey the magnificence of pattern welded swords in small pictures. This link leads to to some large-format pictures showing some replica swords from Patrick Barta. If you do not have the desire to own such a sword, you are a lost cause.

Now to business. If you look long and hard at the picture above, you should realize that any ancient smith who attempted to make blades with patterns like these must have been able to do *two* things on top of what his older colleagues could do, who already could make very good swords by compositional piling. And I don't mean hardening by quenching; that was well-known before pattern welding came into its own.
You see it? No? Fine, I will tell you:

1. The pattern is only *visible* if the two materials used are *quite different.* You may use low carbon and high carbon steel, or wrought iron and phosphorus iron, whatever. What you cannot do is to weld wrought iron to wrought iron or medium steel to medium steel, something the Celtic and Roman sword smiths did quite often as we have seen. There might be a pattern but you won't see it.
   That means that you, the smith, must be able to recognize and select two specific kinds of iron / steel from what's out there, and your error margin must be small.
2. The pattern is only *uniform* if your two steels are uniform. In other words, the carbon (or phosphorous) concentration in one kind must not change going down the blade as it is usually found with the older Celtic or Roman swords. That requires a kind of uniformity that is far better than what you typically have in the pieces you selected. The uniformity needed can only be achieved by substantial folding and rewelding the selected pieces. In other

Special Module

Faggoting

words: you need to do heavy **faggoting.** More to that topic in the special module.

- There are undoubtedly many pattern welded swords out there where the material was not faggoted. They still may have sported a nice pattern because the smith was lucky. There must also have been pattern welded swords with not so good patterns, washed out here and there, and with ill-defined contours. We do not know because extremely few old pattern welded swords have been repolished, so we simply do not know what their pattern looked like. For more or less the same reason we also do not know if the steel used for making pattern welded swords was faggoted or not, see below. We also should not extrapolate from the swords we have to the bulk of swords used a long time ago. What we have tends to be the top-of-the-line products, sacrificed because taken from the Chief or entombed with the Boss. The normal every-day stuff was re-used or re-cycled and just disappeared.

At least one of the Celtic blades (No 12) investigated by Pleiner had essentially a very complex pattern welded structure, quite different from all the other ones. If there isn't a mistake with the dating of that sword, and I don't suggest that there is, we must conclude that all the techniques and skills needed for advanced pattern welding existed several 100 years before pattern welding became mainstream. Why didn't it catch on? Maybe because the uniformity of the welded bars was no good enough to produce a clear pattern all the way? Maybe faggoting was not invented yet?

- This is just idle speculation. We just don't know for sure what these ancient smiths could do with respect to faggoting. Why? As pointed out before, you cannot judge the uniformity of a long bar of steel by just looking at a *cross-section*. You need to look at it *lengthwise*, and that is almost never done because it would "destroy" the whole length of the blade. Whenever it was done with less precious stuff (double pyramid bars, roman iron bars), the stuff was always non-uniform with respect to the carbon and phosphorous concentration. Since the pattern in a pattern welded sword is created by a *defined* difference in the two kinds of steel, typically the phosphorous concentration, fluctuations of the phosphorous concentration would produce fluctuations of the color difference and therefore patchy pattern with washed out parts. Modern smiths do not have that problem. The darkness and brightness of the two kinds of steel is the same everywhere.
  The point I'm trying to make here is that the general switch to making pattern welded swords around the 2nd century AD implies that the long bars welded together must have been reasonably uniform. It just makes no sense to do pattern welding with doubtful materials. Since the blooms and all the semi-products made from blooms were not uniform at all, the smith *must* have used faggoting in one way or the other to achieve uniformity.
  We can be fairly certain about that - and we have a few direct observations. Recently **Stefan Maeder** subjected some old Western swords (Including a pattern welded one) to the Japanese kind of polishing, and that does make faggoting visible up to a point. More to that in the link. Closely looking at Danish bog swords (not easy because the museums mostly keep them in the basement, in the dark, or far behind reflecting glass), one can see clear indications of faggoting; here is an example.

If we mull this over a bit, a major conclusion will emerge:

The end is near.

- A smith who could make a pattern welded sword like the ones shown here around 300 AD - 600 AD has reached the zenith of working with bloomery iron / steel. There is nothing left to improve upon. Such a guy could make *anything* that can be made with iron / steel by hand forging. If you supply him with better iron / steel, he might make a better sword but not because he uses better forging techniques. There are no better ones.

Does that mean that we are close to the last page of the Hyperscript? Not really. I still have to tell you how a pattern welded sword is made, and I will also look into the making of "Japanese" swords and wootz swords. In addition, I will give you some stuff about the properties of sword and the mechanics of wielding a sword.

Basic Ways of Pattern Welding

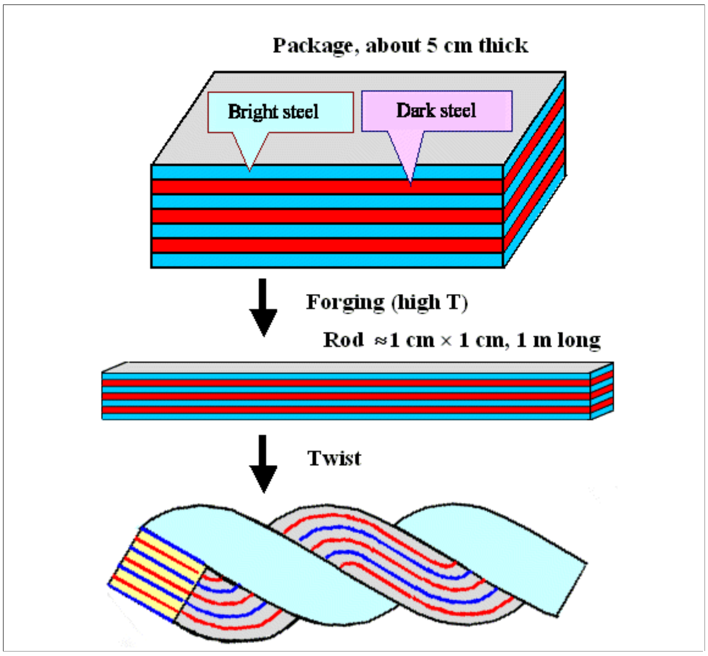
If you want to know almost all there is to know about pattern welding, read the book of Manfred Sachse! It is a marvellous book with lots of high-quality pictures - and there is no way that I can improve on it. So I will give you just a short and very general introduction into what pattern welding is all about in this module. I'm going to look into some more details in the next module.

- Quite generally pattern welding employs butt welding. At least 4 rods are needed, and more than 10 have been employed. Two rods are almost always made from uniform hard steel and are used for the edges of the blade. The rods that will produce the pattern are made from two different steels. A kind of standard often encountered was a package of seven layers; 4 made from "soft" steel, 3 made from "hard" steel. That is the way it is usually described but I put soft and hard in quotation marks because the hardness is not what counts. The effect you are after is a bright -dark contrast in the finished blade and not a hardness difference. The best way to achieve that is to use use phosphorous-rich and phosphorous-free iron, and that seems to be the most common approach for making what I will call a "striped rod". Iron containing sufficient phosphorous has a bright whitish appearance, phosphorous-free iron or steel is dark. In what follows I will therefore use the neutral terms "bright" and "dark" iron / steel.

- What's more: coupling phosphorous-free carbon-lean and carbon-rich steel is not such a good idea. During all the high-temperature smithing required for fire welding, the carbon concentration will more or less equalize by diffusion. There cannot be a well defined color change at the boundaries any more. In contrast, since phosphorous diffuses much more slowly than carbon, the difference in phosphorous concentration is not washed out.

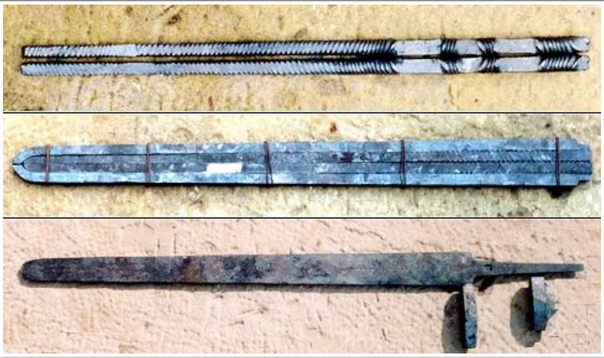
Let's start by making a rather simple pattern welded blade with just three patterned striped rods (two would be the minimum; eight are about the maximum).
What you, the ancient smith, needed to do for a simple pattern welded sword was:

1. Get enough raw material with the following specifications:
   1. *Bright steel*. Phosphorus-rich wrought iron might be best
   2. *Dark steel*. Maybe phosphorous-free medium steel - whatever will provide for a good contrast to your bright steel.
   3. *Hard steel*. Needed for the edge. Your steel should have at least the eutectoid composition (0.7 % carbon). Take the highest carbon concentration you can still work with since you will loose some carbon during forging.
2. Faggot all three materials before you form bars. In other words: hammer into a sheet, fold and weld, hammer into a sheet, ... Repeat 8, 9, 10 , ...times. Make sure that the welds are perfect and that you do not introduce too much "dirt" like oxide, slag or flux inclusions by the welding. In the end make two rods from the hard steel, about as long as the blade to be, and 12 or 9 plates from the bright and dark steel, respectively, about 4 cm x 7 cm wide / long and 7 mm thick.
3. Make three packages from 4 bright and 3 dark steel plates each as shown:



Package, striped rod, and twist

4. Fire weld each package and than draw it out to a rod about as long as the blade to be - as shown above. The cross-section of the rods should be about 1 cm × 1 cm. What you have now is what I like to call a "**striped rod**". It is the starting material for many - but not all - pattern welded swords.
5. Twist the striped rods evenly or, for a more complex pattern, alternate twisted and non-twisted regions, making sure that the alignment of the layers in the non-twisted regions is the same everywhere (striped sides always "up", for example). You many also change the twist directions (clockwise / counterclockwise). Now you have a **twisted striped rod**
6. Put all rods next to each other as shown below (for just *two* twisted striped rods). In the non-twisted regions the layers should be perpendicular to the picture plane so that a stripe pattern can emerge.
   You may grind down the rods somewhat, especially flattening the sides to be joined. You may also want to fit the twisted parts exactly so they interlock like two screws with the same thread. That necessitates, of course, that the pitch of the twist is exactly the same in the two rods, something next to impossible. The two hard steel rods go on the outside. You may want to bend these rods a bit as shown below in order to obtain a snug fit at the end where the point will be.

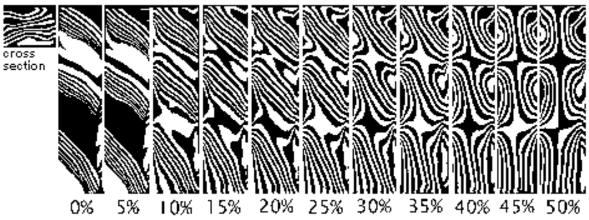


Arranging the rods to be welded, and welding

Source: From the Internet pages of Patrick Barta; http://www.templ.net ; with friendly permission.

7. Fire weld the assembly, making sure that the weld seams are perfect. Forge it into the basic sword shape desired. If necessary, supply a tang by fire welding. Alternatively, extend some of the rods into the tang.
   That gives the raw blade as shown above (together with some parts for the hilt)
8. Make fullers by forging if so desired. Grind the blade, giving it the cross-section desired. Note that the pattern you will get depends on how deeply you grind into the twisted rods.
9. Quench-harden the edges. Before you do that, cover the body with some protective mud (for what is called "differential hardening"), making the cooling rate much larger in the edge part than in the body of the blade. And yes, that is the famous way of making Japanese swords with particularly hard edges. And yes again, our ancestors may have done it too, even so this has not been advertised a lot so far.
   Now temper a bit (annealing at low temperatures) after quenching. Alternatively, keep the quenching time so short that "self-tempering" occurs since the inside is still hot and heats up the outside again after pulling the blade out of the cold quenching liquid. Do some "slag-quenching", in other words.
10. Finish by polishing the blade and exposing the pattern by one way or the other, e.g. by some etching. Allow a lot of time for doing that.
    Add a nice hilt, matched to the beauty and value of the blade.
    Have a beer or two.

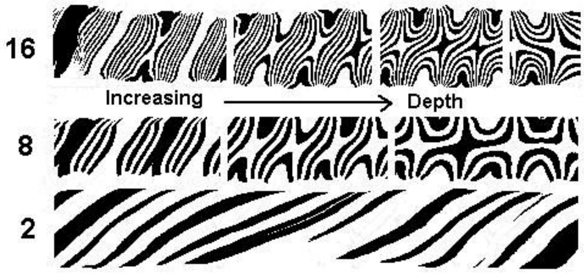
You have now made a *simple* pattern welded blade. Of course, now you wonder what the resulting "**torsion damast**" pattern will look like? I yet have to meet somebody who can imagine what the distribution of bright and dark iron looks like in different depths of a twisted striped rod. You are welcome to figure that out by yourself - but here are the pictures:



Patterns disclosed by successively grinding down the length of a twisted clay model striped rod

Source: Lee A. Jones: "The Serpent in the Sword: Pattern-welding in Early Medieval Swords" 1997; Internet article

The pictures above and below are from an Internet article of Lee A. Jones. The article still makes for good reading; here it is.
The clay model rod in the picture contained *sixteen* alternating layers of white or black clay (and not just seven as in the text); it was prepared by bladesmith Dan Maragni. Note that in making and twisting a striped rod you will not be able to keep the layers exactly parallel everywhere. Some distortion is unavoidable, an example of one real cross-section is shown in the upper left-hand corner.
The striped rod was progressively ground and reduced in overall thickness by the percentages shown in the picture. The pattern at each each interval was *photographed*. so these are real patterns. Further leveling of the striped rod will produce mirror images of the patterns shown
The next picture shows the effect of the *numbers* of layers used.



Pattern variations shown in clay models with 16, 8, and 2 layers

Source: Lee A. Jones: "The Serpent in the Sword: Pattern-welding in Early Medieval Swords" 1997; Internet article

- Once more we have photographs of a clay model striped rod. The two-layer rod shows the pattern after just flattening it with a hammer. No grinding is needed in this case.

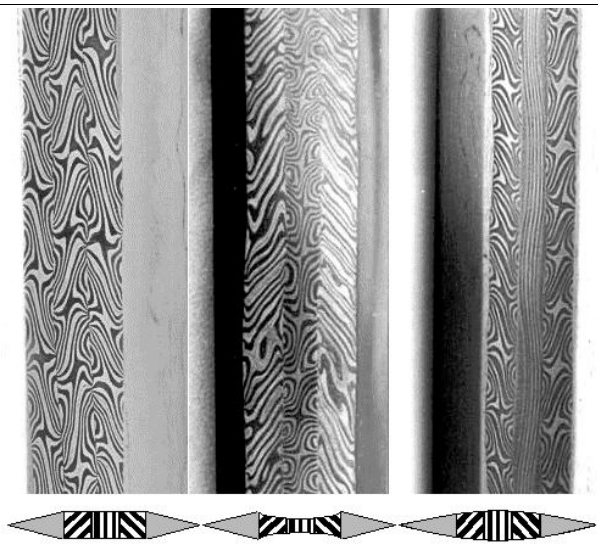
Let's take another look at the structure but now with "theory". What we see below are computed *drawings* of an ideal structure with perfectly parallel layers. The cross-section is indicated on the top of the striped rods.

Ideal pattern variation with depth in a twisted rod

Source: J. Ypey: " Europäische Waffen mit Damaszierung. Archäologisches Korrespondenzblatt 12 (1982) ppp 381 - 388.

- The picture also indicates how one can get an uninterrupted wavy line by proper alignment of perfectly matched rods ("effect" side). This is considerably more involved than just a random alignment, of course.

What we have made might look like this:



Simple pattern welded swords with three twisted striped rods (left)
and two twisted and one untwisted striped rod (right)
Cross-sections do not relate to the swords shown

Source photographs: From the Internet pages of Patrick Barta; http://www.templ.net; with friendly permission.

- Note that the front and back will look about the same. What you get depends on how deep you grind and that depends to some extent on the cross-sectional shape chosen as schematically indicated. How deep you can grind is limited by the thickness of the blade. If you want a thickness of 5 mm in the center, you can only grind off 2.5 mm on each side of a 10 mm rod, of course.
  In other words: you cannot get the more circular or "flowery" patterns deeper down in the rod.

Now that you have made a relatively simple pattern welded sword, you want to try your hand at a more complicated one. You want to have full freedom for the patterns, different patterns on the two sides of the blade, and a very fine pattern. Then we talk about cross-sections like this one:

Complex pattern welded blade

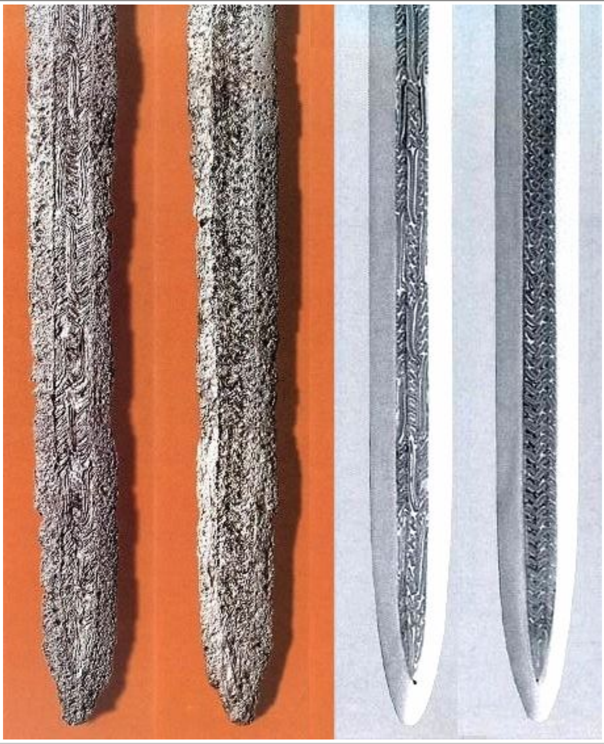
- You make *eight* striped rods with *16 layers* each. You grind down as deep as you want to get the desired pattern on one side (with the final grinding after the blade was forged). You also grind down the backside so you can fire weld these thin rods to an additional core; 4 on the front side, 4 on the back side. You need 64 each of faggoted bright and dark iron plates to start with, plus the centerpiece and the hard steel for the edges.
  What you get is essentially a sword made by piling with a thin **veneer** that produces the pattern. It is clear that the "veneer" could not be all that important for the sword properties; it was essentially just for show. It also concealed all the flaws from imperfect welding, large slag inclusions and so on that might have been visible on the "naked" blade. Here is an example of what a good "naked blade" might have looked like. Putting on some veneer was a definite improvement in looks.

What the real thing might look like is shown below. It is a blade fragment from the Nydam treasure. it is badly corroded and most of the edge part is missing. Nevertheless, it is quite clear that the structure is similar to what is shown above. We have three striped rod on both sides. On one side the rods ware twisted and ground down to reveal a pattern akin to the ones shown above. On the other side the rods were untwisted and thus display a stripe pattern.

Fragment of a Nydam sword with complex pattern welding
Large picture

- "Only" three and not four (partially) twisted layers on one side. But front and backside are now different so we have six twisted layers altogether

Making a sword like this gets to be real work! And extremely skilled work because one mistake, just one wrong bang with the hammer or being a fraction of a millimeter off during grinding, and your blade is ruined.
A whole sword might look like the **Spatha of Ingersheim**:



Ingersheim Spatha [1)]

Source Used with permission

- A lot of different patterns can be produced by (twisted) striped rods; even more than what I have shown here. However, some patterns found in ancient swords need even more involved work; I'll get to that.

If you look at the cross-section above and give it some thought, you realize that in essence you have a sword made from solid steel with a thin "veneer" of patterned stuff on both sides. It is clear that the "veneer" part cannot be of much importance to the properties of the sword. This makes very clear that at least at this stage the pattern welded part is *only* decoration with no function whatsoever for the fighting value of the blade. Its function was in pleasing its owner either by its beauty or because he could afford it, and in sending signals to others about the significance of its owner. In other words: it was a **fashion statement**.
Just give the Stuttgart Psalter a quick look to convince yourself that these sword bearers were fashion conscious:

Fashion around 825 AD

Source: Internet site of Württembergische Landesbibliothek, Stuttgart, Germany

- If you look at the general outfits of those old sword bearers you realize that they were far more into fashion than a typical physicist of our time. They were into fancy, fashionable stuff, about on par with present-day catholic priests or rock stars.

It was important to be fashionable and to show your importance by sporting the proper sword (and scabbard), even if you couldn't quite afford it. That's perhaps, why some pattern welded swords had patterns only on one side. The last "gold-hilt spatha" found around 1970 in Pleidelsheim [1)], South Germany, (increasing the number of known South-German gold-hilt spathas to 18) had gold only on the show side of the sword, like some others. This show-off pattern welded sword belonged to an Alemanni who lived around 550 AD next to my home town. If some no-nonsense fighting was required he probably used the plain sax that was also buried with him.

If you assume that the general attitude towards fashion was not all that different from that of today, you know that the time of the pattern welded sword would be over some time after it had reached its summit. When you can't put more lace around, or tatoos on your neck, because there is simply no more room, you switch to something different sooner or later. Fashion changes might not have been as frequent as today in those more slowly moving times, but changes would occur for sure.

It was thus to be expected that the complex "veneered" pattern welded sword would eventually loose ground to a radical new fashion like the "Ulfberht sword".

- Before I look at the "Ulfberht swords", I will give you a bit more about pattern welded swords and the (pattern welded?) *sax* that was used in parallel to the pattern welded **spatha** as we call all double-edged straight and long swords.

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1) Ingersheim in Ludwigsburg county is a small town at the left-hand side of the river Neckar in South Germany. It actually comes in two parts: Groß-Ingersheim and Klein-Ingersheim. It's one town down-river from the town were I was raised. In 1969 and later in 1988/90 around 250 "Frankish - Alemanni" graves that contained pattern welded swords among many other things were mostly found in **Pleidelsheim** (other side of the Neckar). Ingersheim is also a quarter in not-so-far away Crailsheim.

The **Alemanni** were a confederation of *Suebian* Germanic tribes on the upper Rhine river. First mentioned by the Romans in 213 AD, the Alemanni expanded into present-day Alsace, and northern Switzerland, leading to the establishment of the Old High German language in those regions. In 496 AD., the Alemanni were conquered by Frankish leader Clovis and incorporated into his dominions. The legacy of the Alemanni survives in the names of Germany in several languages; they are more or less my direct forebears.

Stefan Maeder mentions the sword of Ingersheim at least twice. For reasons of his own he refers to it as the sword from Ingersheim / Crailsheim county or Ingersheim / Schwäbisch-Hall county. I do not know where it really comes from but my guess would be Pleidelsheim.