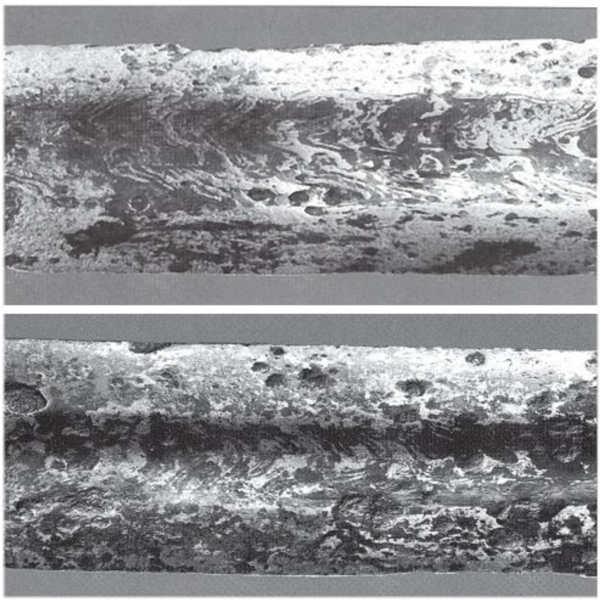
Analyzing the Forging of a "Viking" Sword

Science

What follows is essentially an excerpt from *Joachim Kinder's* work[1] entitled (translated to English) "Damascened sword blades - forged at what temperatures for how long?" I have it under "pattern welding" and not under "Viking swords" because they are not yet typical Viking all-steel swords.
Kinder investigated two remarkably well-preserved blades that were found in the Rhine around 1920. The swords are of the Viking type and pattern welded; they thus date to about 900 AD or somewhat later. One of the swords is now privately owned, one is in the Tower museum in London. The swords are extremely well preserved; here are pictures of sections of the blades:

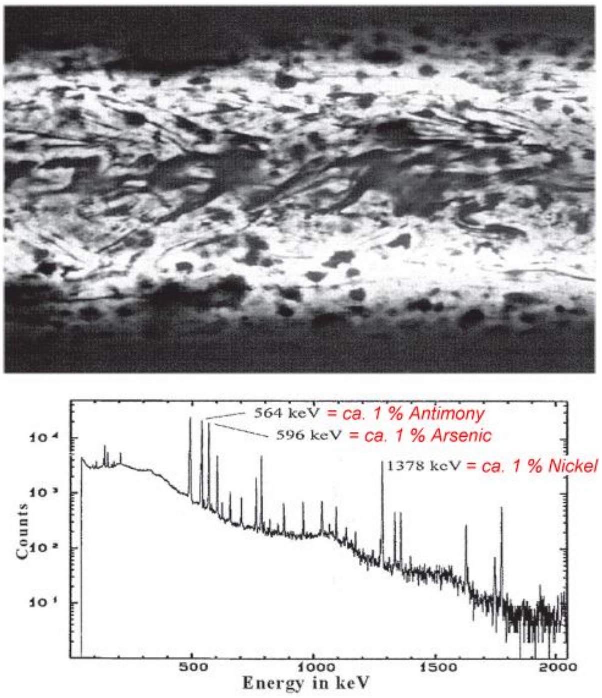


Parts of the swords

- One of the swords had a well-defined pattern, the pattern on the other one looked a bit "washed out".
  Kinder worked at the (huge) "Bundesanstalt für Materialforschung und -prüfung" (BAM) in Berlin when he investigated these swords and had about every known analytical method at his disposal, including a scanning electron microscope that could accommodate a whole sword! He established that the contrast between the dark and bright steels involved phosphorous (P) and set out to determine phosphorous (P) concentration profiles across weld lines with an accuracy that would allow him to determine to what extent phosphorous had moved from the P-rich region to the P-poor region. Given the known parameters of P diffusion that would enable him to find out what kind of temperatures the blade had "seen" for how long or, in other words: exactly how the smith had done the forging of the blade.

Interesting (and not fully understood) first results were:

- X-ray investigations showed a lot of structure and thus a lot of non-uniformity (see below). Remember that the internal structure of a perfect straight or twisted striped rod would *not* show up in X-rays pictures since *all* steels look very much the same to X-rays. If one sees something, it must be due to imperfect (or corroded) welds, slag particles, holes, oxide particles, flux particles, whatever - but not to different grades of the steel.
- A γ-ray activation analysis (you need a nuclear reactor or a substantial particle accelerator for doing this) showed that the blades contain about 1 % of antimony (Sb), arsenic (As) and nickel (Ni), respectively; see below. That can be seen as a clear indication that the smith used some kind of iron - arsenic/antimony alloy with a low melting point as "flux" for joining iron / steel by hammer welding. Note that these elements would be missed by some other analytical methods. They did not show up, indeed, when probed with EDX

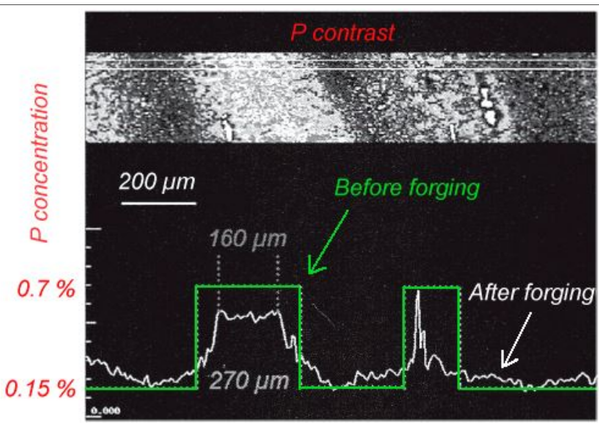


Top: X-ray image of one sword
Bottom: Activation analysis spectrum showing Sb, As and Ni (among other more "normal" elements)

- The twisted pattern is still is clearly visible on the blades since the P-rich parts are hardly corroded at all and even "blued" by oxidation. That probably happened during the last 1000 years but it might also be original.

Appearance of blade at low magnification

- The phosphorous concentration varies between about 0.15 % and 0.7 % from "dark" to "bright" stripes. The concentration profile could be imaged and measured with EDX:



A detailed analysis of all the data lead to the following final conclusion:

- Fire welding took place around 1100 °C (2012 °F); i.e. at a temperature too low for the "normal" SiO_2 flux.
- The phosphorous distribution can be explained by assuming that the blade experienced an *average* temperature of 975 °C (1787 °F) for 14 hours. At 1100 °C a time of 1.5 hrs would be enough. This allows to make an educated guess at how the cycling between welding at high temperatures and forging around 850 °C (1562 °F) must have taken place.
- About 175 heats were needed to forge the blade.
- Keeping the blade just a few more minutes at welding heat than absolutely necessary will produce a washed-out pattern as seen on one of the blades.
- If only the carbon concentration would have been different in the layers of a striped rod, there would be no pattern whatsoever. The carbon concentration would have completely equilibrated throughout the layers of the striped rod. Well - we knew that!

[1)] Joachim Kinder: "Damaszierte Schwertklingen - Wie lange und bei welchen Temperaturen wurde geschmiedet?"; Ferrum: Nachrichten aus der Eisenbibliothek, Stiftung der Georg Fischer AG, Band **77** (2005), p. 99 - 111.