Listen to the Smiths!

Illustration

The "**Sword Forum** International", is an "Internet information website, an educational organization and conservation society, which promotes history and culture through the study of swords and swordsmanship". On occasion it serves as a discussion forum for active smiths.
In 2008 a rather interesting exchange of top practitioners making wootz blades took place . I'll give you almost the complete interchange here; it illustrates several points in the backbone.

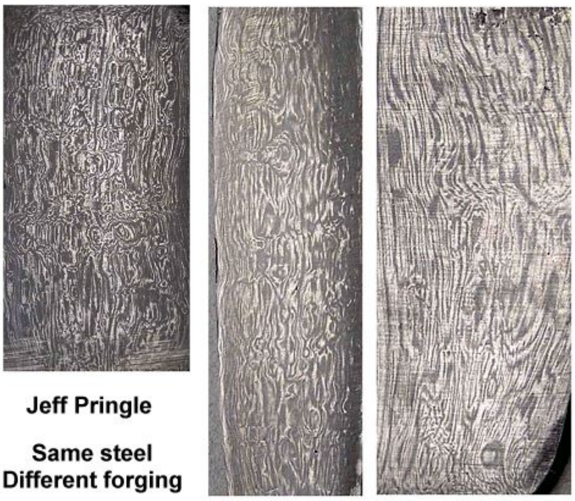
Jeff Pringle, is a well-know smith who makes his own wootz and forges swords, knifes and other things.

Jeff Pringle

Source: East Bay Express; August 08, 2012

Jeff stared a lively discussion with the following remarks (emphasizes are mine)

- Getting back to the subject of this thread, patterns, I think it is safe to say that manipulating the carbide bands in wootz is an order of magnitude more complex than the pattern manipulation involved in pattern welding, not even including the difficulties involved in making the steel in the first place. That said, *it 'aint rocket science*, and after you forge out fifty or a hundred ingots you do get a feel for what makes the bands move, so I imagine the patterns we see in the old swords are far from accidental - they must have been mighty familiar with the material when those swords were made.
  To see if a pattern has more to do with the smith's intentions than the characteristics of the particular ingot he is working, I decided to see how close I could get to a few of the various patterns on the swords in Figiel's "On Damascus Steel", *using a single ingot*. At least, the experiment might show that widely varied patterns can be coaxed out of a single block of *dendritic* steel. The samples are in the 1x2 – 2x3 inch size range, roughly sword-scale.
  Here are the pictures:



Somewhat different patterns made from the same ingot by Jeff Pringle

- Enter **Richard Furrer**, an old acquaintance and the moderator of this discussion forum. Richard runs the Door County Forgeworks. Here he is:

Richard Furrer

Source: Ric's homepage

- He comments as follows:
  - Jeff, Nice work. It helps that you have large banding in that ingot which allows for a greater visual effect when the bands are disrupted. I am interested in a repeat of that large banding from another ingot.
- Next is **Peter T. Swarz-Burt**, who runs the Dragon's Breath Forge and the Fallen Hammer Production. He is also quite able to produce "wootz".

Peter Swarz-Burt

Manouchehr M. Khorasani

Source: Fallen Hammer Production; Internet at lage

Peter remarks:

Jeff, That is some very nice, broad banding you have gotten there! Is this the type of pattern that all your ingots produce? If so, what is your *cooling rate* during solidification? I am currently running on the the theory that the *cooling rate is one of the big deciding factors* in the final pattern, since it will change the type and orientation of the dendrites that form. My ingots always seem to form a much more fibrous pattern, rather than the laminar or *sheet patterns* that we see in the highest quality antique blades.
I want to be clear here that when I am referring to the "pattern", I am talking about the *underlying appearance of the carbide banding rather than the material manipulation patterns*.
In my opinion, manipulating the banding to get a pattern is *not* the complicated part, it is getting the desired type of banding in the first place.

Jeff Pringle answers:

- I typically ramp the furnace down over ~1/2 an hour and cool the crucible in the furnace for up to an hour, but when solidification happens and how long it takes I've never tried to figure out.
  ....
  The underlying appearance of the banding *IS* a material manipulation pattern, the ingots all start out as fibrous, dendritic lumps.
  Here is a *photo* of the first pattern test on this ingot, just forged out without any attempt to alter the banding…
  Is this (picture below) hat you are referring to as 'fibrous' (kind of an extreme example 'cause it was close to the end of the bar, where the least amount of forging happens as you transition from ingot to barstock - I like that dendritic appearance, kind of "modernist wootz"?

Early wootz from Jeff Pringle. Fibrous pattern?

Peter T. Swarz-Burt clarifies:

- Here is reasonable picture of the pattern I am referring to. The blade pictured is a clay-coated and water-quenched tanto (short Japanese sword) that I made up as an experiment, and the carbides in the hardened region were rendered invisible in the etch.
  Anyway, you can see the *fibrous pattern* that I am talking about pretty well in the picture. The carbides, rather than appearing as sheets or ribbons appear as strands.
  In some blades that I have done ladder patterns and really cut across the grain of the material, the end-grain appears as a lattice of squares or rhombuses similar to your picture above, but much finer and tighter. My best guess is that this is a factor of *solidification rate*, but so far my attempts to slow this rate haven't yielded the pattern I am aiming for.
  I had one ingot five or six years ago *that did what I wanted,* but for the life of me I can't figure out what I did differently that time.

- Jeff Pringle comments:
  - Changing solidification rate might allow you to adjust the size of the pattern, by altering the original dendrite spacing, but that is the *only* effect I think you'd see. Beyond that, you may well find *alloy make-up* and *forging technique* are more fertile ground for theorizing about patterns…and a whole lot of ingot forging can't hurt, either.
- Peter T. Swarz-Burt *disagrees* to some extent:
  - The cooling rate actually has a *huge effect*, since rate of solidification completely changes the way in which the dendrites form, not just the spacing between them. Rapid solidification yields a fairly uniform distribution of 3-dimensionally random crystals, while in very slow cooling the dendrites tend to align themselves to a much greater degree.
    In the steel industry an ingot that cools too slowly and alligns too well is said to have "*ingotism*" and these ingots are extremely difficult to forge without cracking.
    I think the questions I am trying to answer is whether the best looking of the antique wootz came from ingotism or from a faster cooling technique...after all, there aren't any good numbers that I have been able to find that detail just how slow is too slow/slow enough.
    As I said in one of my earlier posts, I have gotten the same fibrous pattern in every ingot except one, and that is saying something when I am talking about one out of about 35. Plenty of people have made more than this, but so far nobody I have talked to has been able to look at the fibrous patterns I am getting and say "Yeah, I used to get that and changed X to Y and now I get this.
    I have varied my mixes, varied my forging techniques, changed heat ranges, etc. and still I am getting the same effect. Doing additional material manipulation adds more interest to the pattern, but the underlying structure remains fibrous.
- Now **Greg Thomas Obach**, a "Honorary Academic Advisor on Wootz steel" and a Canadian smith who started forging around 1999 as a pastime, comes in.
  Greg runs the "North Shore Forge & Ironworks" and has done a great job in hiding himself. There are no pictures of him in the Net - but a lot of pictures relating to his wootz.
  Below is an example of his work, "a marvelous shamshir", according to **Manouchehr M. Khorasani** (shown above), a well known expert we have met before.

Greg Thomas Obach's wootz

- Here are Greg's comments

- I think just changing x to y maybe *too simple* to make a swoopy kinda pattern.. .. i'm thinking its a combo of several factors and those pend on the alloy... this is just my loose thoughts.. by no means written on stone...
  It maybe pattern depends on:
  1) *Structure initially solidified*.... coarse to fine dendrites pending on cooling time and alloy
  2) *Roast/anneal/stress relief* ...... an additional heat treatment to help the forgeability of the ingot... and moving around of some elements
  3) Forge cycles and reduction... .. how big are your cycles and how many.... and how much forging was done..
  4) How its *heat treated*... .. effects how it etchs
  5) *Etching*... if you don't use the right acid for the right wootz.... you will see very little of the watering.... some etches work in different ways..
  The most *dendritic ingots* I forged... one had no anneal and a arc welded casing ... second was pressed out with a short roast.. - first one had almost the exact pattern the top of the ingot had... so honestly... i get one sorta swoopy pattern every 3rd ingot..... .. the other two are kinda half way... or dendritic.. *i have some plans to try and get to the bottom of this* ... it would be nice to generate some data ..... even use some stats to try and pin down some effect ... which is obviously hard to observe.. do you hand hammer out your wootz...? from ingot all the way down to blade?

Jan Ysselstein , another (hobby?) smith working with wootz, now comes in and remarks in general and to Richard "**Ric**" Furrer in particular:

- It helps that you have large banding in that ingot which allows for a greater visual effect when the bands are disrupted. I am interested in a repeat of that large banding from another ingot.
  "
  Ric, I think I know what you mean by large banding but I am not sure. Just started examining old cakes and older failed cakes for contrast. If I have such material around I want to make sure I recognize it. Thanks Jan

Ric replies and elicits an answer as follows:

- *Ric to Jan:*
  The final look depends upon the *spacing of the cementite*, their *size* and then how you *manipulate* those bands (ladder, drill bit holes..even peening with the hammer etc).
  I have had single dendrites be 2" long in larger ingots and remain more or *less unchanged, but stretched*, in the final blade. The blade that Jeff forged had a very nice banding...good space between and good contrast from matrix to carbide...this is not the norm in modern wootz. Jeff did something different.....its up to him to backtrack and reproduce the effect
  Jan to Ric:
  Thank you. If we look at a "wootz cake" and see a clearly defined dedritic structure, are the visible cementite areas at the location of the "*carbide formers*" ? Assuming they are *not*, does that mean we can not know if the banding is tight or large until we forge the cake?
  By the way I think Jeff has posted all the details of his experiment and I kind of enjoy the challenge this is presenting to us, so I think it is now up to all of us to reproduce the effect. We are all *very, very close*, I am sure. His experiment has suggested several variations for me to try soon, the trouble is, they are so darn expensive to do. How boring it will be to log on to one of these sites and have everyone post a perfect "wootz" pattern.

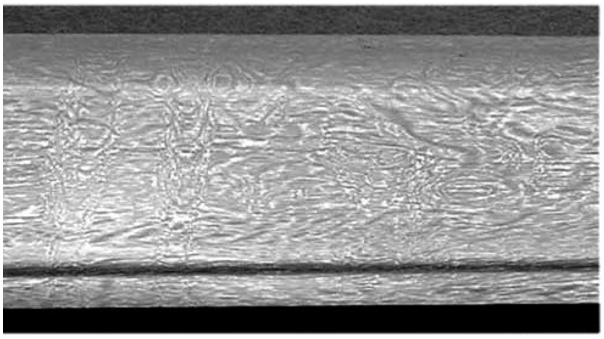
This brings in Peter Swarz-Burt again, with remarks to Jan eliciting an answer

- *Peter to Jan:*
  My own experience is that *the initial dendritic structure*, while certainly a predictor of the final pattern, *is definitely not the whole story*. After all, if you look at the picture of one of my typical ingots versus those of Jeff's typical ingots, there isn't much difference to see. Yet Jeff seems to be pulling off a nice laminar pattern (wish I knew how), while my own ingots always forge down with a very fibrous pattern (wish I knew why). When compared to the very "broad" and "open" patterns seen in the Persian blades, neither mine nor Jeff's matches the look. Mine is very different because the underlying structure of the pattern is different, while Jeff's is different not in structure, but in degree.
  To go with a "wood grain" comparison here, the Persian blades show a very open and well defined grain, Jeff's show a tighter but still well-defined grain (smaller "growth rings"), while mine comes from an entirely different kind of tree, perhaps a black Palm. One is not necessarliy superior to the others, but I think we can all agree that the spectacular patterns (like the one I posted early in the thread) are the goal of all our strivings. Maybe I am mistaken in this, but I know it is what I am aiming for.
  On your original question, I do think that the dendritic pattern in the ingot is a predictor of the eventual "broadness" of the pattern, *since the carbide bands are definitely forming along the initial dendrite lines*. This is *especially easy to see* at the ends of a wootz bar, where the material has been forged the least. In these areas, the original dendrite matrix is still quite visible, and it can be seen to blend into the pattern of the remainder of the bar. In many cases, material removal patterns such as ladder and pool and eye will also reveal areas of this dendritic pattern elsewhere in the blade, indicating that this dendritic pattern may be hidden, yet present, throughout.
  Jan to Peter:
  Thanks for the reply. Jeff's patterns have looked "unique" for a long time, but he has just hit on something quite different (possibly to his surprise). The latest pattern is a look I would like be able to create. So all I can do for the time being is, hypothesize what he did and what may have created the change (Jeff has shared his details with all

of us). I kind of enjoy experimenting at very high temperatures, so not knowing is not driving me crazy. Meanwhile I just keep reading to learn to explain what it is I am looking at though the magnifying glass.

Jeff Pringle now comments on all of the above:

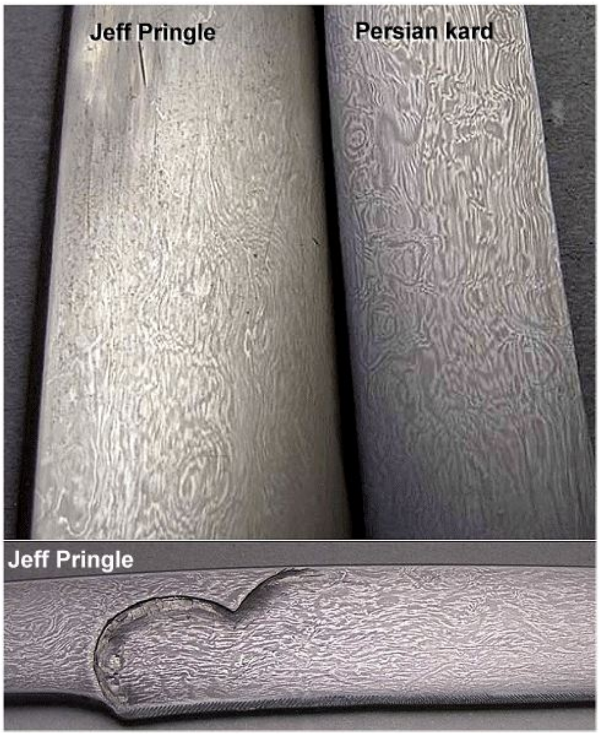
Hi Jan! Nice to 'see' you over here, maybe we should wootz-brainstorm in your mountain retreat, there are so many variables to eliminate it would help to have an idyllic setting to keep focussed
FYI I'm going to cook up some ore this evening over at Jim's. To get the real wootz patterns, first thing you got to do is take that western music off the stereo and put something more Persian on while you forge. Homayoun Shajarian, Anis Moin, Mahasti or Shakila should get your dendrites to relax, and the rest is all in your hammering.
I too think *the scale of the pattern is set by the size of the dendrites*, visible on the ingot surface. Unfortunately I have not taken a lot of ingot photos, so it's hard for me to come up with a matched set of several photos of both the ingot and a blade forged from it – that could be the proof right there, so I'll start taking photos of ingots if you guys will – make sure there's a ruler or scale reference in the shot. And speaking of scale, I like the 'wood grain' analogy, but I think we all know who has the superior wootz around here – Greg is the only one hand hammering every ingot all the way, that's a whole lotta care and attention and I think he gets the nod for superior dedication to doin' it old school. My ingots only get that much love on special occasions. Unless, Greg, it is just because you don't have an air hammer?
Regarding the size of the tree rings, my ingots usually yield blades with patterns of about the same scale as the old Indian & Persian blades, for instance this blade I'm trying to finish up this week (different ingot from the one used for the pattern tests, but they were Persian-size too) matches up well with an antique jambiya made from large-scale Persian wootz that I keep around for reference, and has a bigger pattern than a Persian wootz kard and Indian wootz tulwar that are my 'medium' and 'small' references. As soon as I get a little more Persian style in my swirls I'll take some side-by-side photos.
Did you send any metal to the lab yet, Peter? Is your process uniform enough for you to say a test on one ingot will tell you something about untested ingots? I have a hunch that banding quality (clarity, contrast, maybe more) is heavily influenced by minor changes in chemistry.



Jeff Pringle's wootz

Jan Ysselstein responds and gets a reply:

- *Jan to Jeff:*
Verhoeven states dendrite spacing in cast steel may *as great as 1mm*. My cakes are only at about *half that distance at best* (however I have a textbook photo of a single crystal of steel (iron) which seems to be an exception to that rule). I have a sample of iron (part of a higher carbon smelt) which has a structure I would love to see in a crucible melt (very crisp areas of cementite contrasted with what I believe is pearlite). Yes, Geg is "de Man" when it comes to forging the unforgable (please don't tell him I have just cut 4 lbs off of a 10 lb. sledge), he has made a significant contribution to our collective understanding of this material. Today I will be attempting to forge some scraps of wootz in order to learn what I can before remelting.
Jeff to Jan
Forging scraps is good, you can learn a lot from a limited amount of material, especially if you have scraps from a few ingots lying around. Most of my fragments are no longer tied to a specific smelt in my brain, though, so some potential knowledge can be lost unless you have a filing system for your spare ingot parts. Here is today's scrap experiment, next to an antique Persian kard and one from last week that presumably came from a faster-cooled ingot, it's got a finer structure but looks like it will make a sweet knife anyway, once the carving is done.



Jeff Pringle's wootz and an antique Persian kard (= knife, dagger)

- Jan Ysselstein replies:
  - Jeff, both of those pieces look really good, the one with the carving looks like you have just left the dendritic look....*I think you've got it*. That was a good way to spend a day.....I spent it fumbling a cake of wootz with tongs in a charcoal fire (and often on the floor) , hitting it with a 12 lb. sledge (cut handle) and virtually having no impact on its' shape at all. I am very nervous about proceeding too fast with the brittle chunk.....sooooo much time and money has been invested, I will just plug along until the steel tells me it is ok to speed things up. It is becoming clear to me why so few people continue to attempt wootz...you would have to be crazy.
- Peter Swarz-Burt makes the closing comment:
  - So far I have not had any chunks sent out to the lab for testing for reasons that can best be summed up as "laziness". This is the result of having too many other, more important (ie money making), things to do, thus procrastination sets in. Melting ingots and forging them into blades is fun and exciting, calling around to find a good lab that can run the tests on the cheap is not fun. However, my formula is pretty simple and I have stuck pretty close to it for several years now.
    Basically it can be boiled down into gray cast iron (haven't been able to find a local source for high purity pig iron), mild steel, and a small chunk of *vandium-bearing tool steel*...generally W-2. I calculate all my ingredients with a carbon percentage of around 1.5% in mind, although this varies somewhat, generally to the high side. I use fireclay crucibles to avoid picking up carbon or silicon, and run a simple slag of mixed green and clear glass over the top. I don't cover my crucibles, since I like to be able to poke a mild steel probe into the mix to check for full-melt...my furnace achieves high enough temps after about 1-1/2 hours, but I always like to be absolutely certain.
    When I first started out I was shutting down the furnace and closing up all ports to achieve a slow solidification, but more recently I have taken Greg's suggestion and run multiple crucibles in a single day, one after the other. This means that I am shutting down and waiting about 10 mins for full-solid, then popping one crucible out and dropping the next one in.
    I think the next time I do a run I will try to drop the furnace temp to around 2200F (1204 ^{o}C) and hold there for 10 mins, then turn off and cool a bit further to be sure...I have accidentally moved partially liquid ingots in the past and it makes for some very strange shapes. After the ingot is completely cool, generally the next day, I pop it into the propane forge and *let it "roast"* for at least an hour. This was another suggestion from Greg, and it definitely improves the forgeability of the ingot. My guess is that the re-crystallization helps "blur" some of the potential fracture planes created by the slow solidification. To help in this I often *heat cycle* my ingots a number of times during this process. Most of my forging is carried out in the orange to bright orange range, and as I mentioned before this is all under an air hammer. I typically get some minor cracking in the portion corresponding to the top-center of the ingot, but I have assumed this was the result of impurities (sulfur and phosphorous, mainly) from the cast iron concentrating in this area.
    Does anyone spot something in here that says "Aha! this is why the pattern is so fibrous rather than laminar."