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Whatz Wootz?

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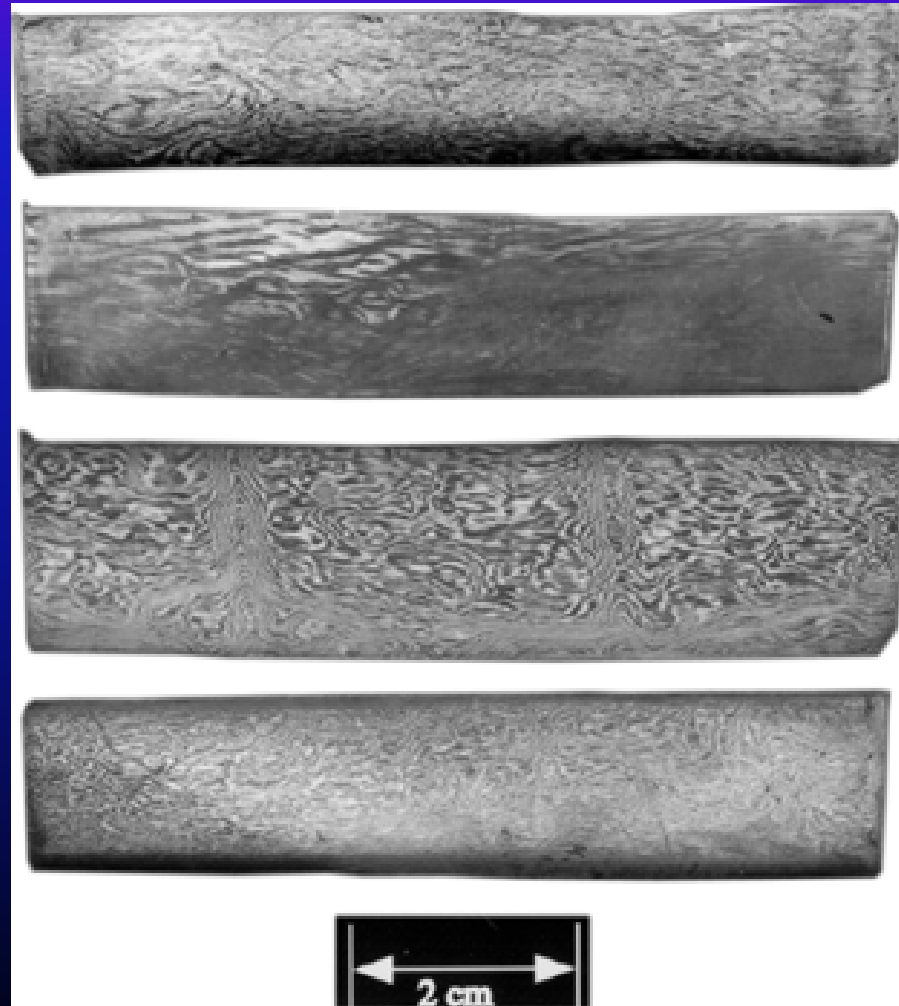
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Wootz Steel

- Wootz is the steel from which Damascus blades were forged.
- It does not refer to the pattern welded blades which are also called Damascus blades.
- The Wootz steel was smelted in various parts of India as early as 200 BC.
- The Wootz “cakes” were traded to many parts of the world for use in swords and knives.
- The word “Wootz” is a corruption of the Kanada Indian word “ukku” which is pronounced “WooKoo”

What's Special about Wootz?

- Wootz is known for the intricate pattern that is developed in the steel.
- While the pattern is etched on the surface to make it visible, the microstructure that causes the pattern goes all the way through the metal.

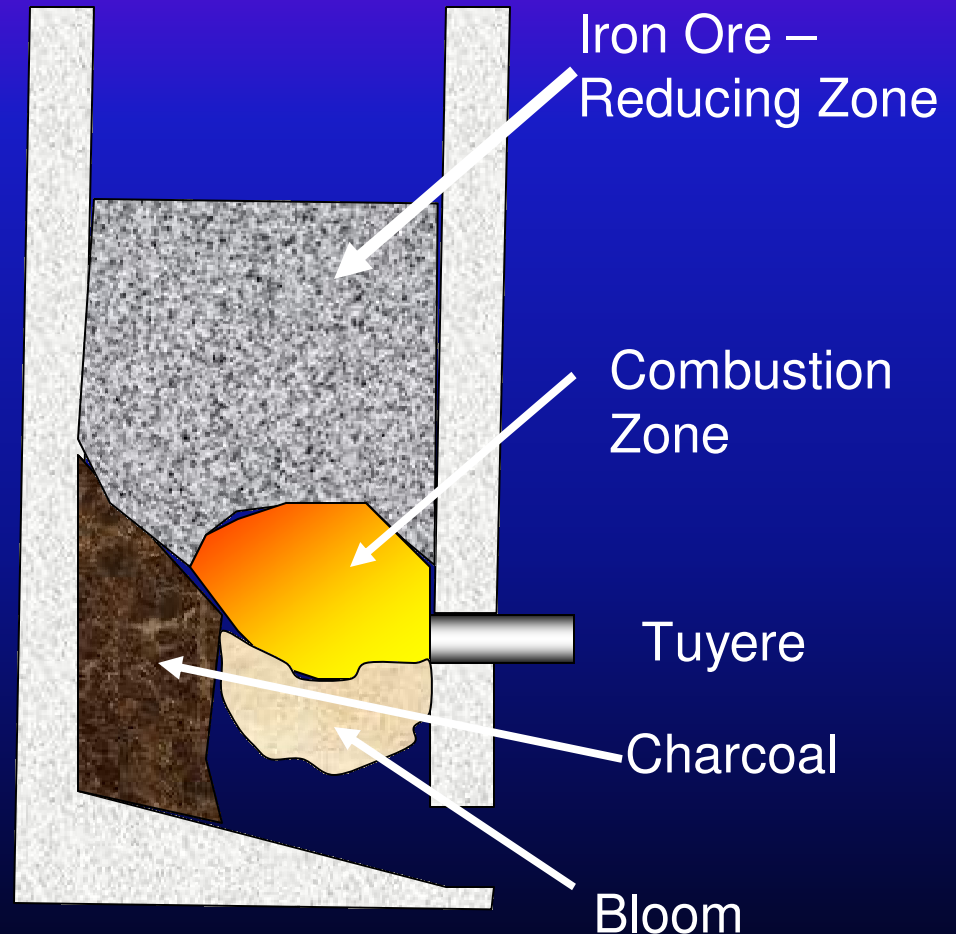


A Brief History of Wootz

- Alexander the Great is said to have been given 100 talents of Wootz steel.
- Wootz was traded all over the known world for centuries but only a few places knew how to forge it into blades.
- Damascus, Syria was the most noted center of Wootz Blades.
- Areas in India also made fine Wootz blades.
- There is another technique call pattern welding that can appear similar to Wootz but relies on layer of high and low carbon steel being welded together and forged to make the wavy patterns.

How Wootz was Made

- Iron Ore from the deposits in Southern India was smelted using a traditional bloomery furnace.
- Charcoal was burned to generate Carbon Monoxide which reduced the iron oxide ore to iron.
- The iron, along with the silica from the ore, collected in a blob at the bottom of the bloomery,



How Wootz was Made

- Charcoal is used to pre-heat the bloomery furnace.
- Iron ore is crushed and placed on top of the charcoal.
- The charcoal is superheated with forced air and begins to convert the ore to iron by the following equation:



Bloomery Iron

- A bloomery furnace could not reach a temperature sufficient to actually melt the iron that was produced in the furnace.
- The iron was mixed with up to 2% silica slag as a remnant of the silica contained in the ore.
- After the bloom was removed from the furnace, it was very porous and had to be pounded by hand to consolidate the iron and extrude the slag. Hammering was done while the bloom was still very hot.
- The result was an iron with almost no carbon.

A Bloomery Furnace

- A modern reproduction of a traditional shaft bloomery furnace.
- Charcoal and iron ore were layered into the furnace, set on fire and more charcoal and ore were fed into the top over a period of several days.



A Bloomery Furnace

- A bloom of spongy iron, slag and clinkers is removed from the furnace.



Bloomery Iron



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Processing the Bloom

- After cooling, the bloom was broken up into pieces.
- Pieces were placed into a crucible along with organic matter like charcoal, leather pieces, etc.
- The crucible was sealed and placed into a furnace to be heated for many hours.
- The heat vaporized the carbon in the organic and it was absorbed by the iron.
- The result was an iron with up to 2% carbon.

Wootz Cake

- A modern replica of a traditional Wootz cake.



Wootz Cake

- Close up of ingot surface showing dendritic pattern.



Forging the Wootz Cake

- Because of the very high carbon content, many smiths did not know how to forge the cakes.
- At white-hot temperatures normal for the wrought iron they were used to, the cakes just crumbled.
- At this temperature, the carbides in the Wootz melted and the steel fell apart.

Nothing Says Lovin' Like Wootz From the Oven!

- To make them forgeable, the Wootz cakes were packed in crucibles with Iron Oxide (scale) and heated to about 2300F and slow cooled in the furnace.
- The scale cause the surface of the Wootz cake to lose carbon and form a decarburized layer on the surface of the cake.
- The soft, ductile iron “rim” would hold the Wootz steel together while it was being forged.
- Interestingly, the earliest Wootz blades WERE NOT QUENCHED AND TEMPERED!
- The microstructure of early blades was that of pearlite with carbides precipitated in across the grains of metal.

Forging Wootz

In his treatise on replicating Wootz, Greg Obach used the following forging steps to work the cake.

http://dark.unitz.ca/~gthomas/myweb4/replication_of_wootz.htm

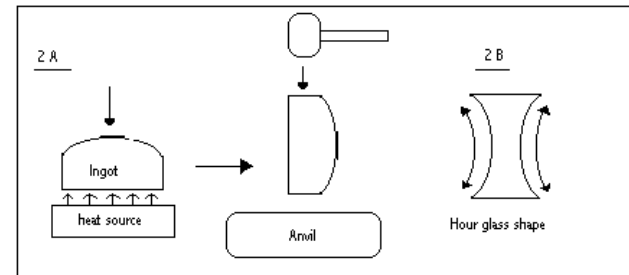


Figure. 2.

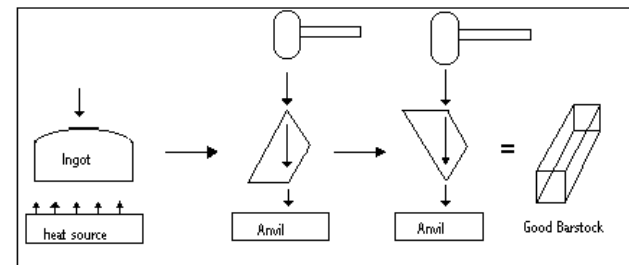


Figure. 3.

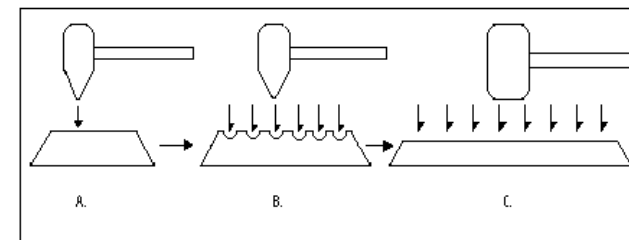


Figure. 4.

- The following steps were used to actually forge his Damascus Blades.

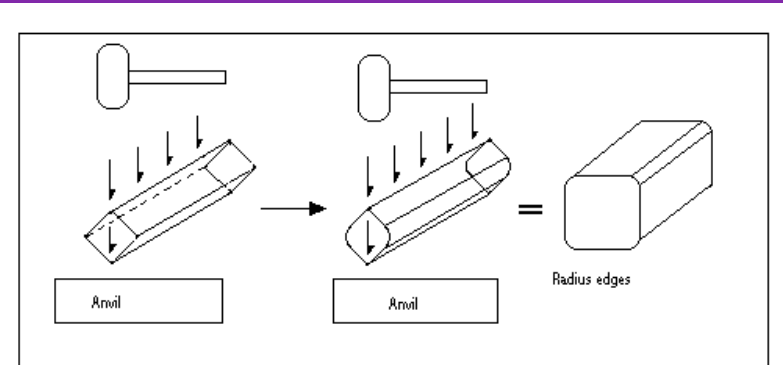


Figure. 5.

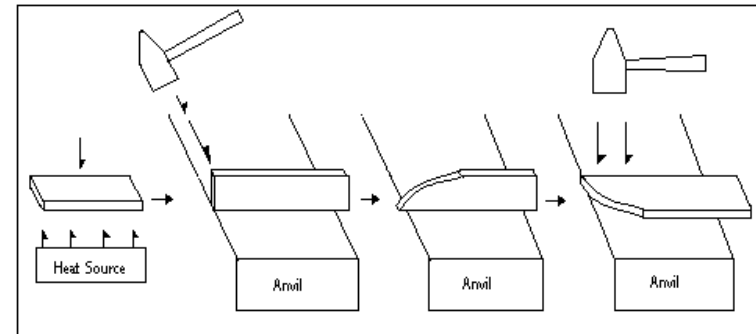


Figure. 6.

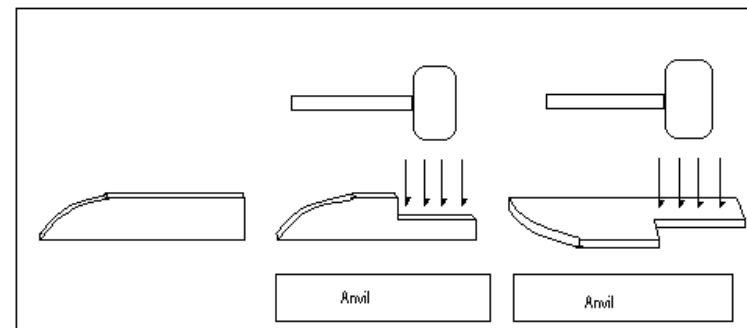
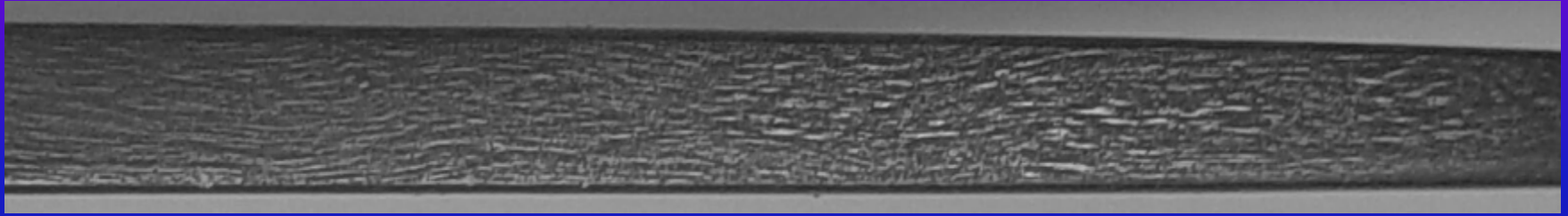
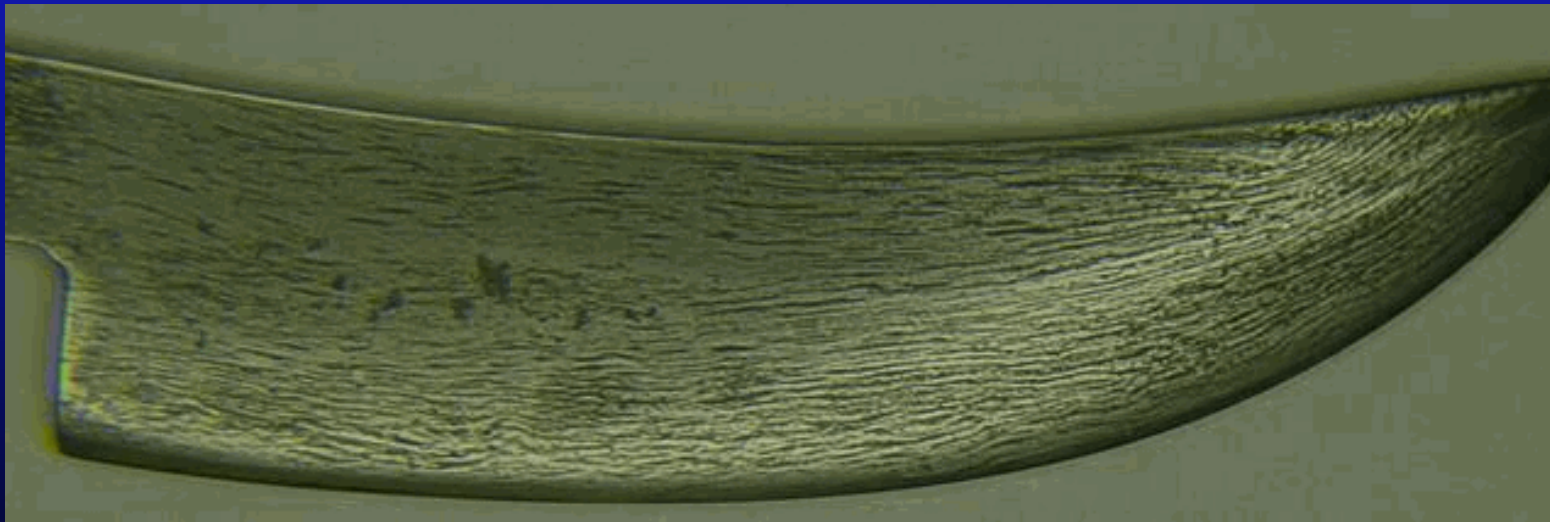


Figure. 7.

A Modern Wootz Blade



Etched longitudinal face of blade 1. Hammer planished and treated with ferric chloride. The spine is observed under a 6x magnification.



Nitric acid etched blade, hammer forged bevel on blade edge, 2x magnification.

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What Makes That Pattern?

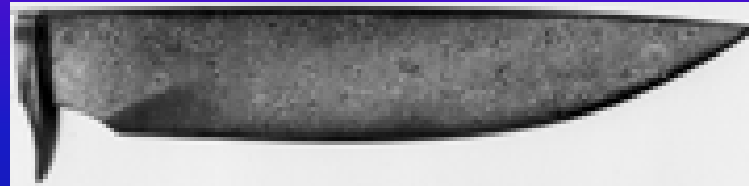
- In a strange circle of events, the fascination with Wootz sparked a lot of interest in trying to discover its secrets.
- England in the 17th century was in the midst of an industrial revolution and a scientific revolution.
- The interest in Wootz provided considerable motivation that led a new science: Metallurgy.
- However, the secret was not really discovered until Metallurgy was over 100 years old.

The Secret

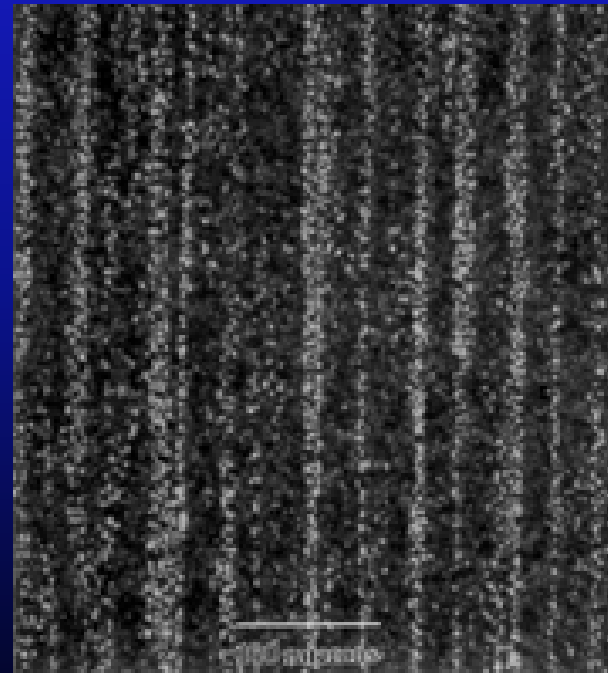
- The secret is impurities in the ore.
- The ore was found to contain a very small amount of the rare element Vanadium, a strong carbide former.
- The vanadium was not added to the ore, it occurred naturally; even the Indian craftsmen had no idea why the pattern was in their steel and not others.

The Verhoeven Paper 1998

A reconstructed Wootz Damascus blade showing the Damascene surface pattern containing a combined Mohammed ladder and rose pattern.



A longitudinal section of the same blade showing the bands of cementite particles responsible for the surface pattern.

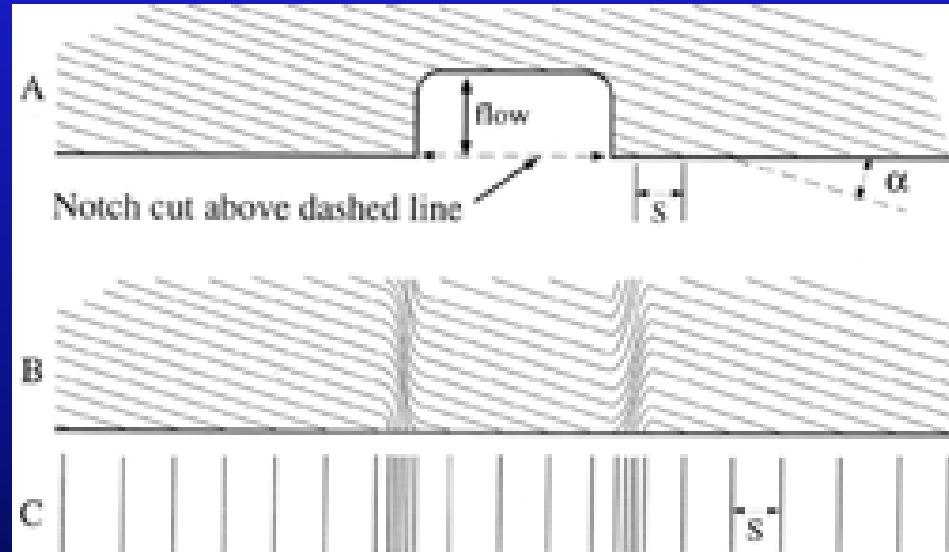


Manipulating the Pattern

(a) A longitudinal section view after a notch cut across blade.

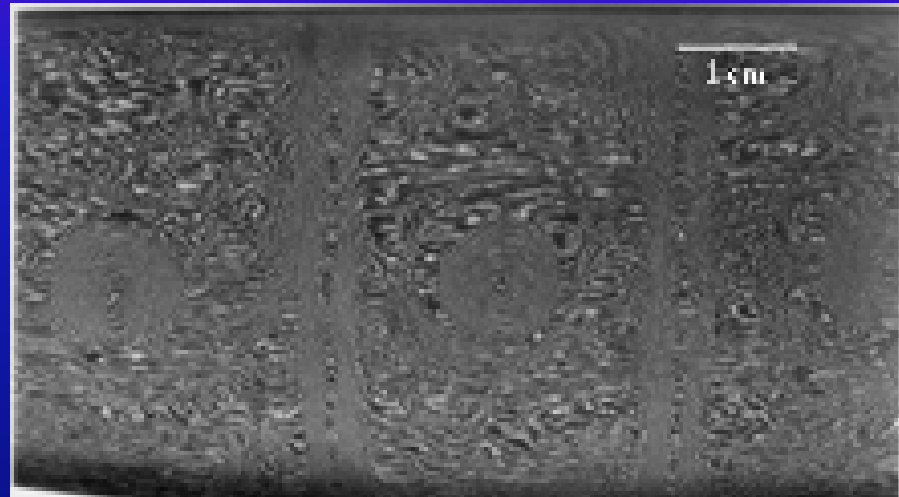
(b) Distortion of the carbide bands by forging flow.

(c) A schematic of the blade surface showing band spacing after forging flow.



Detail of the Pattern

The ladder and rose pattern produced by (a) grooves cut into the surface of the nearly finished blade and (b) grooves forged into the surface of the nearly finished blade.



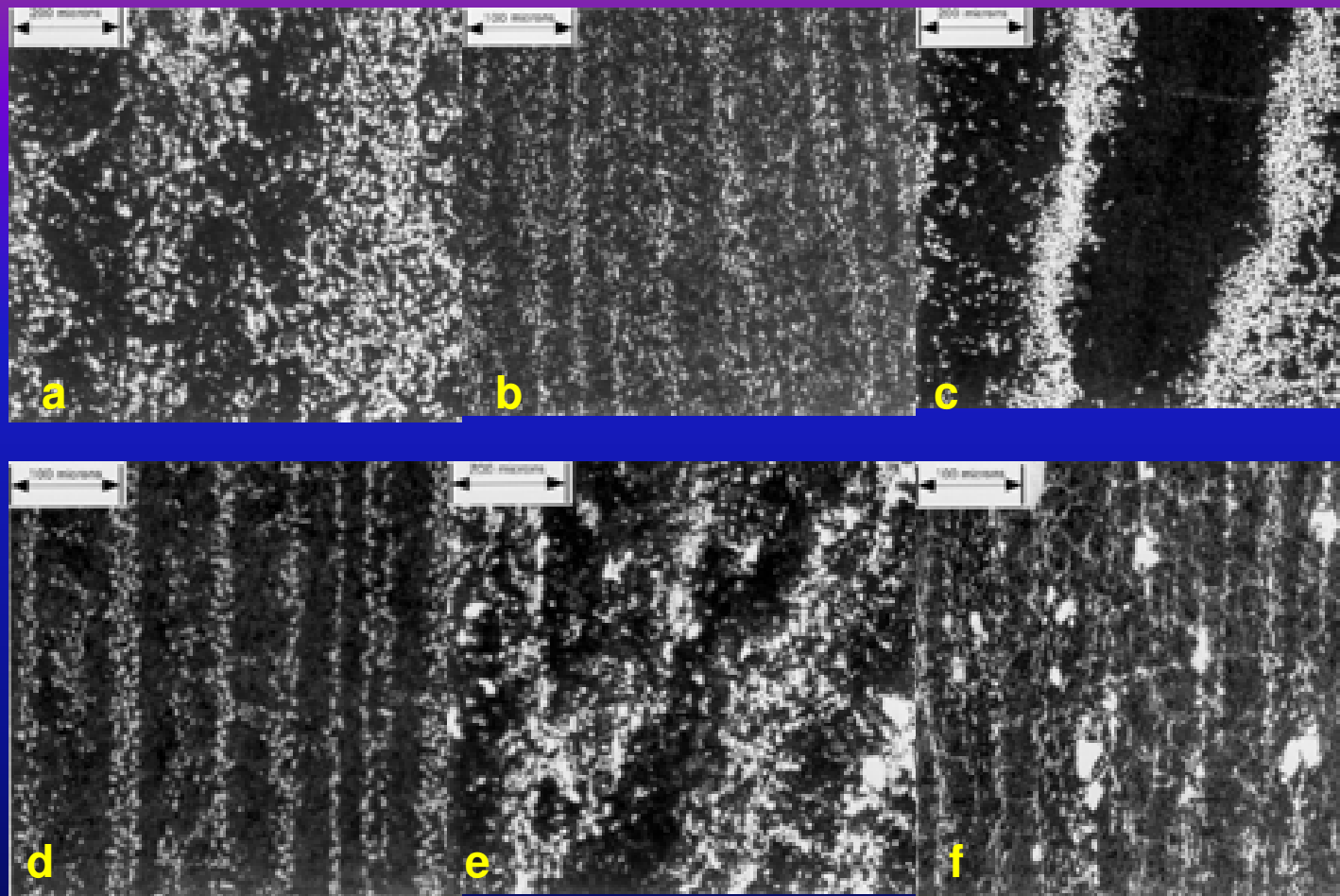


Figure 3. Micrographs of Zschokke blades showing (a) the surface of blade 7, (b) a transverse section of blade 7, (c) the surface of blade 9, (d) a longitudinal section of blade 9, (e) the surface of blade 10, and (f) a transverse section of blade 10. From the VerHoeven Paper

Why the Art Was Lost

- When the vanadium bearing ore ran out, Wootz steel could not be duplicated.
- Since no more Wootz cakes could be produced, the people who forged them died out and the methods were lost.
- The interest in learning the secret to Wootz led to the development of the science of Metallurgy.
- Modern metallurgical science solved the mystery but without Wootz to spur its development, metallurgy might never have been born!

What did we learn from the
Ancients?

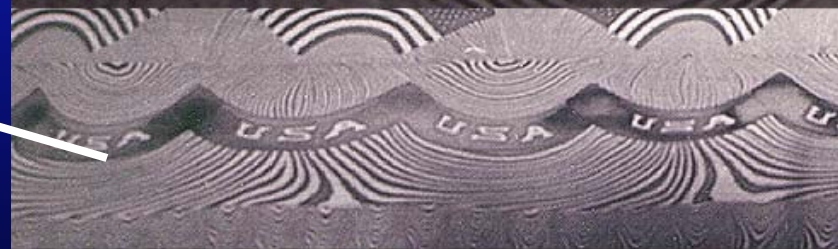
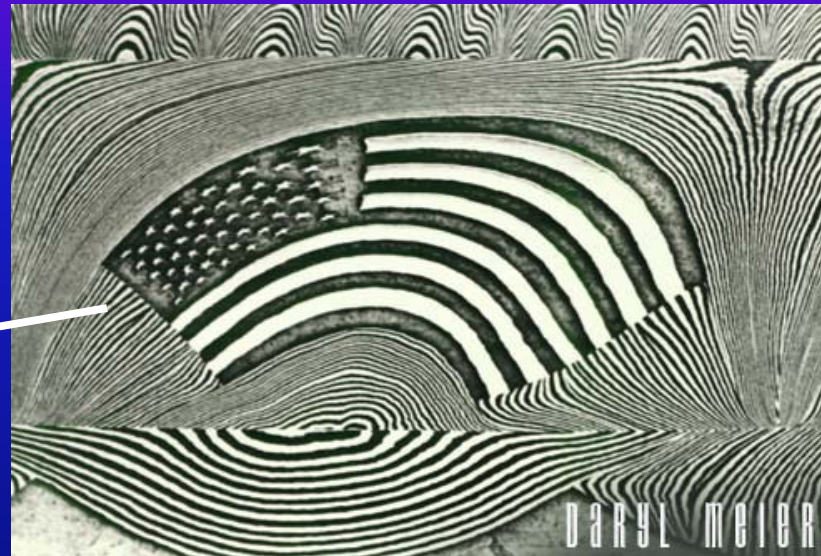
Have we progressed?



A genuine ancient Damascus Blade

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Modern Blades-Meier Steel



This knife was presented to President GHW Bush by Daryl Meier, bladesmith and metallurgist.

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The End

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