The Great Verhoeven - Wadsworth Jousting Tournament

Illustration

Setting Up the Tussle

Research into the basic understanding of metals in general and steel in particular took on a new quality around 1970. There are many reasons for this but in my opinion the main reason was the advent of the electron microscope. Transmission electron microscopes allowed to look inside the metal, revealing the wonders of the micro- or better nanostructure with dislocations, precipitates, grain boundaries and whatnot. The scanning electron microscope extended the limits of the regular optical microscope and, more important, allowed "microprobing", i.e. displaying the *local* concentrations of alloy and trace impurity elements.
It was predictable that some of the scientists would use the new equipment and insights to tackle the old mystery of wootz steel and "watered" blades.

- One of the first was Prof. Dr. Ing. **Carlo Panseri** , who published a very detailed study titled "Damascus Steel in Legend and Reality" as early as **1962**. The paper goes far beyond just wootz blades and is based on electron microscopy. I give you the full text here. Panseri had major insights and we find a lot of good stuff in his paper that was forgotten and only rediscovered 25 years later or so. I will get back to this

In **1979** **J. Oleg D. Sherby** and **Jeffrey Wadsworth** published "*Damascus Steel Rediscovered?* " in a somewhat obscure journal. Sherby, a Professor in the Materials Science and Engineering Department of Stanford University, was the senior researcher; by now he is retired. Wadsworth - then a Consulting Professor - had an astounding career. Since 2009 he is President and CEO of Battelle Memorial Institute, heading more than 22.000 employees doing applied R&D.

- Both of them were into ultra-high carbon steel (UHCS) research. In 1978 they "were made aware that the typical composition of carbon in UHCS is essentially the same as in Damascus steel swords of ancient times, i.e., about 1.4 to 1.8%C. These weapons were renowned for their fine cutting edge and high toughness; that is, they were highly resistant to cracking. Perhaps even more important, they were famous for the incomparably beautiful surface markings which gave the weapon a mystic and spiritual feel. The method of their manufacture by blacksmiths of ancient times is believed to be a lost and forgotten art. An effort was made to reproduce such markings on UHCS materials, and after success was achieved, the published procedure was described as the modern rediscovery of Damascus steel making", writes Wadsworth in 2000 (see below)

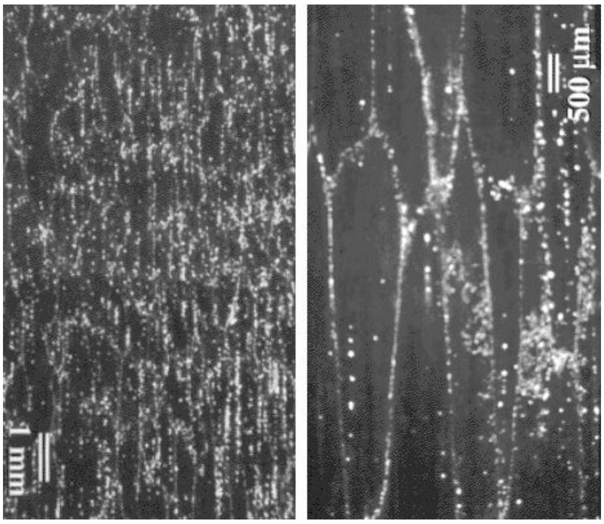
  So what did the two re-discover? That you can make a visible pattern with just about *any* USHC by following this recipe:

  1. First, the wootz (in this case, a UHCS containing over 1.5%C) is heated to near its incipient melting point (a white heat ~1200°C) to develop coarse iron grains.
  2. Second, the wootz is cooled very slowly, over a period of several hours, to form a thick continuous network of iron carbide at the boundaries of these coarse iron grains. At this point, surface markings are visible to the naked eye consisting of spherical grains with a thick border of iron carbide.
  3. Third, the wootz is heated to a color between blood red and cherry (i.e. about 650 to 750°C), a temperature at which the iron carbide network will not dissolve, and the wootz is then mechanically worked extensively to break the network into individual, coarse, iron-carbide particles that are spherical or elongated. The network is now no longer continuous, but remains visible as a layered structure, and is very appealing to the naked eye.

J.Oleg D. Sherby with Marilyn in 1997

Source: Homepage of "The Order of the Damask"

- There is no doubt that this works. You get patterns like this:



"Sherby / Wadsworth Structure" in UHCS Steel

Source

- We have a working recipe. But *why* does this kind of pattern develop? I think I can explain this quite nicely and I will even do it somewhat later.
  Then you might just turn to the work of **Käthe Harnecker**, who produced patterns just as good as the one above already in 1924.

First let's ask ourselves: is that pattern the *real* thing? It's not as *nice* as some of the patterns found on old wootz swords. I will not explain what I mean with "nice" since there is no better way of classifying "good or "bad" patterns. You know it when you see it. Wadsworth's patterns are also only shown for a small area and not for a whole blade.
Anyway, Wadsworth, Sherby plus assorted coworkers kept pursuing their newly discovered hobby (besides their real jobs) and published a string of papers:

1979	**Wadsworth**, J., and O.D. **Sherby**, Annual Bulletin of the Metals Museum 4 **1979** p. 7 - 23.
	Oleg D. **Sherby**: "Damascus Steel Rediscovered?" Trans. ISIJ, 19(7)**1979** p. 381--390.
1980	J. **Wadsworth** and OD. **Sherby** , “On the Bulat - Damascus Steels Revisited”, Progress in Materials Science. 25 **1980** p. 35 - 68
1983	Oleg D. **Sherby** and Jeffrey **Wadsworth**: "Damascus Steels --- Myths, Magic and Metallurgy", The Stanford Engineer, Fall/Winter **1983-84**, p. 27 - 37.
	J. **Wadsworth** and O.D. Sherby, "Damascus Steel Making", Science , 216 **1983**, p. 328-330.
1985	Oleg D. **Sherby**, T. Oyama, Kum D. M., B. Walser, and J. **Wadsworth**: "Ultrahigh Carbon Steels". J. Metals, 37(6) **1985** p. 50 - 56.
	Oleg D. **Sherby** and Jeffrey **Wadsworth** : "Damascus Steel", **Scientific American** , 252(2) **1985** p. 112 -120.key

Being asked to write an article for the Scientific American is akin to being knighted by the Queen of England!
So everything about the water pattern in wootz steel is cool now?

Jeffrey Wadsworth

Avaunt and Hurra!

- Enter **John. D. Verhoeven**, Professor of Materials Science and Engineering at Iowa State University (and now a distinguished Emeritus). He begged to disagree and threw down the gauntlet in **1987**, challenging Wadsworth and Sherby to a veritable joust; just with pens and not with lances and swords.
    - As he writes himself: "My interest in these wootz Damascus blades was inspired mainly from the writing of C.S. Smith [1)], In his extensive review presented in chapters 3 and 4, Smith presents evidence that the blades were forged from the Indian steel known in the West as "wootz" and states : "there can be little doubt that the water is primarily a result of the structure of the cake of wootz or similar steel from which the blades were forged". Smith documented the evidence of the many, largely unsuccessful, attempts of European scientists to reproduce the patterned blades from forged ingots', Perhaps more intriguingly there was an **international conference at New York University in 1985** at which it was concluded that there was no known bladesmith who could successfully reproduce a wootz Damascus blade. Concurring in this decision were Smith and G.N. Pant from the National Museum in New Delhi. Smith had come to the conclusion that the surface patterns resulted from formation of primary carbides (Fe_3C) in the dendritic structure of the wootz ingots from which the blades were forged. Smith had an exchange of letters-to-the Editor of Science magazine in 1983 with Wadsworth and Sherby who put forth an alternate theory. After reading these papers I thought it likely, based on my research experience in metal alloy solidification, that both might be incorrect and began to think of experiments to examine possible mechanisms of the pattern formation."
    - **A comment from the side line:** The "international conference at New York University in 1985" invoked by Verhoeven got it wrong, at least up to a point. There was a smith who had made blades with *wootz-like* patterns as early as 1924: **Käthe Harnecker**, already mentioned above, working in Solingen, Germany. Not to mention the Russian Anosov who manufactured (maybe) "wootz" swords much earlier. Käthe Harnecker also gave an explanation of how the pattern is formed that comes rather close.
      However: What Käthe obained is not what I termed a "nice" wootz pattern, and what Anosov produced I don't know becasue I have never seen a good picture of his "wootz" so far.
- Two papers were written in 1987 and many more ever since.
  Verhoeven, in short, claims:

  1. It is not sufficient to have broken-up cementite particle in the starting UHSC that align themselves to a pattern upon rolling or forging if you want a "nice" pattern.
  2. You need traces of certain elements (vanadium is best) in your starting material that act as nucleation centers for the carbide particles that form later.
  3. The needed inhomogeneous distribution of the carbide particles in the blade results from an inhomogeneous distribution of the crucial impurities in the starting material, and that comes about because:
  4. Something that happens during the dendritic solidification of the original melt.
  5. This might already be sufficient for producing a pattern. For the formation of a *nice* pattern you need in addition several temperature cycles during (low temperature) forging,

  Note that up to a point the whole tournament is not about how you can make a pattern, but only about how you can make a "*nice* " pattern, akin to those found on ancient blades.
  Here are Verhoeven's publications:

1987	J.D. **Verhoeven**, "Damascus steel, part I: Indian wootz steel", Metallography, 20 **1987** p. 145 - 151		
	JD. **Verhoeven**, L.L. Jones, "Damascus steel, part II: Origin of the damask pattern Original", Metallography, 20 **1987** p. 153 - 180		
1990	D. T. Peterson, H. H. Baker, J. D. **Verhoeven**, “Damascus Steel: Characterization of one Damascus Steel Sword”, Materials Characterization, 24 **1990** p. 355 - 374		

	Verhoeven JD, Baker HH, Peterson DT, Clark HF, Yater WM.,"Damascus steel, part III: The Wadsworth-Sherby mechanism", Materials Characterization 24, **1990**; p. 205	
	Abstract: Several blades have been forged from a Fe-1.6 wt% C alloy after heat treating to form austenite grain boundary allotriomorph (GBA) cementite (Cm). This is the Wadsworth-Sherby technique [2] proposed as the mechanism for forming the pattern on Damascus blades. Both the forging temperature and the severity of metal flow during forging were systematically varied. The pattern obtained were compared to a genuine Damascus sword and shown to be macroscopically somewhat similar, but microscopically quite different. **It is concluded that the Wadsworth-Sherby technique is probably not the technique used by ancient blacksmiths to produce the Damask pattern in their blades**.	**John D. Verhoeven**

That was a direct hit! Wadsworth and Sherby had no choice but to gird their loins and charge! While they prepared for battle, Verhoeven kept attacking

1992	**Verhoeven** JD, and **Pendray** AH , “Experiments To Reproduce the Pattern of Damascus Steel Blades”, Materials Characterization, 29 **1992** p. 195 - 212
	Verhoeven JD, Peterson DT., "What is Damascus Steel?", Materials Characterization, 29 **1992**; p. 335 - 341
	Verhoeven JD, **Pendray** AH., "Experiments to reproduce the pattern of Damascus steel blades", Materials Characterization 29 **1992**; p. 195 - 212

Watch out! - Here they come!

Source: Manesse Codex from around 1300

Here comes the countercharge:

1992	Jeffrey **Wadsworth**, Oleg D. **Sherby**: "Comments on 'Damascus steel, part III: The Wadsworth-Sherby mechanism' by Verhoeven et al.", Materials Characterization, 28, **1992**, p. 165 - 172

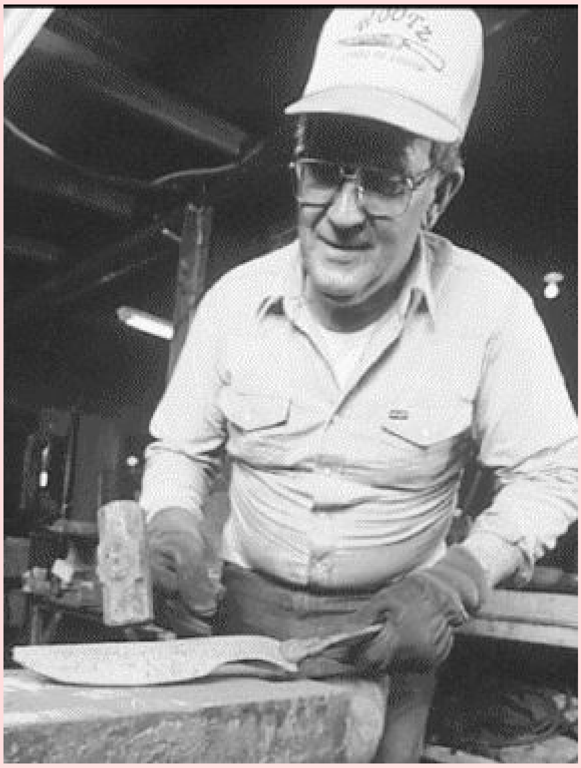
Abstract: The recent article by Verhoeven et al. criticizing the Wadsworth-Sherby (W--S) mechanism for developing genuine Damascus steel patterns is reviewed. It is concluded that the experimental processing methods originally proposed and described in detail by W-S were not in fact followed by Verhoeven et al. in their attempts to duplicate the W-S results. Furthermore, the findings of Verhoeven et al. are complicated and confused by the fact that the baseline Damascus steel, selected by them for comparison with their own experimental studies, is certainly not a typical Damascus steel.

A mighty blow!
Verhoeven responded by allying himself with the blacksmith **Al Pendray** who started making and forging wootz steel and fought back.
The tournament is still on. Here is a progress report:

1993 J. D. **Verhoeven** and A. H. **Pendray**: "Studies of Damascus Steel Blades: Part - Experiments on Reconstructed Blades", Mater. Char., 30 **1993** p. 175 - 186.

Verhoeven JD, **Pendray** AH, Berge, PM, "Studies of Damascus steel blades: Part II - Destruction and reformation of the patterns", Materials Characterization 30 **1993**, p. 187 - 200

Abstract: Two genuine Damascus steel blades and two reconstructed Damascus blades have been austenitized to the point where all of the cementite particles responsible for their Damask pattern were dissolved into the austenite. It is demonstrated that subsequent thermal cycling causes the reprecipitation of cementite particles in the same sheetlike morphology of the original blades, provided that the austenization temperature is low enough to avoid homogenization of the major impurity elements. Mn, Si, S, and P. The results provide strong support for the hypothesis of Part I [Materials Characterization 30:175–186 (1993)], that the formation of sheets of clustered cementite particles in geniune Damascus blades is a type of carbide banding caused by microsegregated third elements deformed into sheets during the cyclic process. Several thermal cycling experiments on reconstructed blade pieces are presented. The experiments support a model in which the third-element additions bias the nucleation of cementite particles into the sheet geometry, followed by enhancement of the sheet morphology by particle coarsening during the thermal cycles



Al Pendray

J.D. **Verhoeven** and D.T. Peterson, What is a Damascus Steel?, Mat. Char. 29, 335-341

J.D. **Verhoeven** , A.H. **Pendray** and P.M. Berge: "Studies of Damascus Steel Blades; Part I Destruction and Reformation of the Pattern", Mat. Char. 30, **1993** p.187-200

1994 C.K. Syn, D.R. Lesuer, and O.D. **Sherby**: "Influence of Microstructure on Tensile Properties of Spheroidized Ultrahigh-Carbon (1.8 Pct C) Steel" Metal Mater. Trans. A, vol. 25A, **1994**, p. 1481 - 1493.

This is serious research stuff where we read, for example:

"In the mid-1970s, it was demonstrated that a class of steels now known as ultrahigh-carbon steels (UHCSs) could be made to behave superplastically" The steels are plain-carbon steels containing between 1.0 and 2.1 wt % carbon (15 to 32 vol % cementite, Fe_3C). Traditionally, steels of such a high-carbon content have been neglected by industry because of a belief that they are inherently brittle. Steels of this composition, however, do have a rich and fascinating history; that is, they are possibly a rediscovery of Damascus steel".

1995 Oleg D. **Sherby** and Jeffrey **Wadsworth**: "Damascus Steel and Superplasticity -- Part I: Background, Superplasticity, and Genuine Damascus Steel". SAMPE Journal, 31(4) **1995** p.10 - 17.

Oleg D. **Sherby** and Jeffrey **Wadsworth**: "Damascus Steel and Superplasticity -- Part II: Welded Damascus Steels", SAMPE Journal, 31(5) **1995** p. 32 - 39

1996 J.D. **Verhoeven**, A.H. **Pendray**, E.D. Gibson, "Wootz Damascus steel blades", Materials Characterization, 37 **1996** p. 9 - 22

E.M. Taleff, C.K. Syn, D.R. Lesuer, and O.D. **Sherby**: "Pearlite in Ultrahigh Carbon Steels: Heat Treatments and Mechanical Properties" Metall. Mater. Trans. A, **1996**, vol. 27A, pp. 111-118.

Serious stuff around the "divorced eutectoid transition" once more.

1997 Eric M. Taleff, Bruce L. Bramfitt, Chol K. Syn, Donald R. Lesuer, and Oleg D. **Sherby**: "Mechanical Behavior of an Ultrahigh-Carbon Steel Exhibiting a Damask Surface Pattern", in Donald R. Lesuer, Chol K. Syn, and Oleg D. Sherby, editors, Thermomechanical Processing and Mechanical Properties of Hypereutectoid Steels and Cast Irons, Warrendale, PA, TMS, September **1997**, p. 189 . 198, Key

O. D. **Sherby** J. **Wadsworth**: "Ultrahigh Carbon Steels, Damascus Steel and Superplasticity" This paper was prepared for submittal to the 9th International Metallurgical and Materials Congress Istanbul, Turkey June 11-15, 1997

Abstract: The processing and mechanical properties of ultrahigh carbon steels (UHCSS) have been studied at Stanford University over the past twenty years. These studies have shown that such steels (1 % to 2.17 % C) can be made superplastic at elevated temperature and can have remarkable mechanical properties at room temperature. It was the investigation of these UHCSS that eventually brought us to study the myths, magic, and metallurgy of ancient Damascus steels, which in fact, were also ultrahigh carbon steels. These steels were made in India as castings, known as wootz, possibly as far back as the time of Alexander the Great. The best swords are believed to have been forged in Persia from Indian wootz. This paper centers on recent work on superplastic UHCSS and on their relation to Damascus steels.

Wadsworth, J., and O.D. **Sherby** in Thermomechanical Processing and Mechanical Properties of Hypereutectoid Steels and Cast Irons, eds. D.R. Lesuer, C.K. Syn, and O.D. Sherby (The Minerals, Metals & Materials Society, 1997).
Review UHSC

1998 J.D. **Verhoeven** , A.H. **Pendray** and W.E. Dauksch: "The Key Role of Impurities in Ancient Damascus Steel Blades", J of Met. 50, No. 9 **1998** p.58-64

Verhoeven JD, Gibson ED., "The Divorced Eutectoid Transformation in Steel", Metall Mater. Tran. A 29 **1998** p. 1181.

Abstract: Experiments are presented which show that the eutectoid transformation in steel can occur by two different modes for temperatures just slightly below A1. In the normal mode, the transformation product is lamellar pearlite. The second mode occurs if the austenite contains cementite particles or nuclei with a spacing on the order of a few microns or less. In this case, the transformation product consists of spheroidal cementite particles in a ferrite matrix. This second mode is here called the divorced eutectoid transformation (DET), after recent work by **Sherby** and co-workers.
These studies, as well as those of **Sherby** and coworkers, do not address the question of the kinetic mechanism of the transformation and do not present micrographs showing the nature of the transformation front for this eutectoid transformation.
The ingot material was forged to a blade shape and, as has been discussed elsewhere, microsegregation of the low levels of V, Cr, and Ti in the ingot produced the unique microstructure of Damascus steel. This is a banded structure consisting of bands of clustered cementite particles lying parallel to the forging plane and separated by bands of pearlite in normalized blades.

Verhoeven fights back in the serious stuff compartment!

J.D. **Verhoeven**, H.F. Clark, "Carbon Diffusion Between the Layers in Modern Pattern-Welded Damascus Blades", Materials Characterization, 41, **1998**, p. 183 - 19

J.D. **Verhoeven**, F. Laabs, A.H. **Pendray** and W.E. Dauksch: "Microsegregation and Banding in Hpereutectoid Steel: Damascus Steel", ISS Transactions, Iron and Steelmaker, 25, No. 11 1**998**

1999 O. D. **Sherby**: "Ultrahigh Carbon Steels, Damascus Steels and Ancient Blacksmiths" 39 **1999** p. 637 - 648.

2000 John D. **Verhoeven**: "A Review of Microsegregation Induced Banding Phenomena in Steels", JMEPEG 9 **2000**p. 286-296

Abstract: A review is presented of banding in hypoeutectoid and hypereutectoid steels. The data available on hypereutectoid steels are quite limited and therefore a study is presented on banding in a 52100 steel. Similarities and differences are identified in the banding that occurs in commercial hypoeutectoid versus hypereutectoid steels. The distinct surface patterns of Damascus steels, which are nearly pure hypereutectoid steels, have *recently* (??? Käthe did that 75 years ago) been shown to be due to carbide banding. It is shown that the carbide banding in the 52100 steel occurs by a distinctly different mechanism than the carbide banding of the Damascus composition steels.

J. **Wadsworth**, D.R Lesuer: "Ancient and modern laminated composites — from the Great Pyramid of Gizeh to Y2K", Materials Characterization, 45, **2000**, p. 289 - 313

Abstract: Laminated metal composites have been cited in antiquity; for example, a steel laminate that may date as far back as 2750 B.C., was found in the Great Pyramid in Gizeh in 1837. A laminated shield containing bronze, tin, and gold layers, is described in detail by Homer. Well-known examples of steel laminates, such as an Adze blade, dating to 400 B.C.can be found in the literature. The Japanese sword is a laminated composite at several different levels and Merovingian blades were composed of laminated steels. Other examples are also available, including composites from China, Thailand, Indonesia, Germany, Britain, Belgium, France, and Persia. The concept of lamination to provide improved properties has also found expression in modern materials. Of particular interest is the development of laminates including high carbon and low carbon layers. These materials have unusual properties that are of engineering interest; they are similar to ancient welded Damascus steels. The manufacture of collectable knives, labeled “welded Damascus”, has also been a focus of contemporary knifemakers. Additionally, in the Former Soviet Union, laminated composite designs have been used in engineering applications. Each of the above areas will be briefly reviewed, and some of the metallurgical principles will be described that underlie improvement in properties by lamination. Where appropriate, links are made between these property improvements and those that may have been present in ancient artifacts.

Jeffrey **Wadsworth**: "The Evolution of Ultrahigh Carbon Steels — From the Great Pyramids, to Alexander the Great, to Y2K", paper submited to TMS Annual Meeting; The Minerals, Metals, & Materials Society Nashville, Tennessee March 12-16, 2000

Abstract: Hypereutectoid steels containing between about 1 and 2.1 wt%C, and now known as ultrahigh carbon steels (UHCS), have both a rich history (dating back to the time of Alexander the Great, i.e. ~300 BC) and an interesting, recent, technological period of development (from 1975 to the present). The connections between the modern UHCS and their ancient counterparts, and in particular Damascus steels, have received considerable attention. In addition to monolithic products, UHCS have also been used in both ancient and modern times in laminated composites. In the present paper, a summary of the modern development of UHCS and UHCS-containing laminates is given, and parallels are drawn with ancient materials. Also, ancient laminated composites containing other steels are described; controversial issues and a possible solution related to the age of such a laminate found in the Great Pyramid of Gizeh are discussed.

J. **Wadsworth**, D.R Lesuer: "The knives of Frank J. Richtig as featured in Ripley's Believe It or Not!", Materials Characterization, 45, **2000**, p. 315 - 326

Abstract: Unusual claims, resulting from “secret” heat treatment methods, surround the toughness and sharpness of the knives manufactured during the 20th century by a cutler named Frank J. Richtig. Richtig became famous because of his dramatic demonstrations of the toughness of his blades by hammering them through iron and steel objects and then illustrating their subsequent sharpness. Two of Richtig's blades have been examined and their microstructure and mechanical behavior determined. Comparisons with contemporary steels of similar composition, which are themselves related to ancient Damascus steels, have been made. As a result, proposals regarding Richtig's “secret” heat treatments are given. Some comments are made regarding historical methods of testing blades and thereby provide a context regarding the degree of difficulty in mimicking the remarkable toughness and cutting properties described by Richtig. Finally, some observations are made regarding the contemporary specialty knifemaking industry in the U.S.

2001 John D. **Verhoeven**: "The Mystery of Damascus Blades", Scientific American, Vol. 284 **2001** p. 74-79

Shrewd hit! Verhoeven now is a knight of the *Scientific American order*, too! You also cannot send letters to the editor of the Scientific American to complain about your competition.
The other side responded by:

E.M. Taleff, B.L. Bramfitt, C.K. Syn, D.R. Lesuer, J. **Wadsworth**, O.D **Sherby** : "Processing, structure, and properties of a rolled, ultrahigh-carbon steel plate exhibiting a damask pattern", Materials Characterization, 46, **2001**, p. 11 - 18

The article gives a recipe for making damascus steel or wootz. Verhoeven and Pendray took issue with this and rode another direct attack in a short and to-the-point *comment* in the "correspondence" part of the next issue of Materials Characterization:

Verhoeven JD, **Pendray** AH "On Origin of the Damask pattern in Damascus steel blades", Materials Characterization, 47 (**2001**) p. 79

They made two points: First, the Wadsworth - Sherby recipe for making "damascus steel" doesn't work, and second, it wouldn't produce a "genuine" damascus pattern, i.e. the layered structure necessary for what I called a "nice" pattern.
This was followed by an immediate answer by Wadsworth and Sherby, published in the same issue:

J. **Wadsworth**, O.D. **Sherby**: "Response to Verhoeven *comments* on Damascus steel". Materials Characterization, 47 **2001**, p. 163 - 165

The authors claim, of course, that Verhoeven and Pedray did not use their recipe / method properly. While that might be true enough (it's next to impossible to duplicate the forging of a wootz sword *exactly* in an independent experiment, especially if trace amounts of impurities etc. are important), the authors weasel on the second point. That is understandable, too. Their recipe, if properly executed and wih some luck, will certainly produce the necessary cementite precipitates. If it produced the layered structure necessary for a "nice" pattern is a matter of pure luck, however. It might happen or it might not; look up the "banding" module if you want to get ahead a bit. Otherwise the article thrives on technical details, insinuating that the "complex" recipe to make wootz that Verhoeven / Pendray followed might, more or less involuntarily, follow parts of their recipe.
This incited a third letter to the editors, also published in the same issue of Materials Characterization:

Verhoeven JD, **Pendray** Origin of the Damask pattern in Damascus steel blades", Materials Characterization, 47 (**2001**) p. 42 - 424

The authors admitted that they did not follow the Wadsworth - Sherby recipe to the letter but to the scientific spirit and that they should have obtained the pattern. The rest of the discussion is somewhat technical, too, and emphasizes the necessity of a proper layered structure that is rather persistent and reappears even if the precipitates are dissolved in between forging steps.

A comment from the side line: This is true scientific jousting! In the good old times that was rather common and used to be done in two ways:-

1. At conferences, in particular during the discussion part. A whole session might have been devoted to some disputed issue and it usually contained duels of the squires (nowadays known as or Ph.D. students). One guy supplied evidence for one point of view (that of his boss, of course). The next guy criticized it and presented conflicting evidence. The knights themselves delivered coups de grace from the side lines during the discussion. Their own jousting was done between plenary lectures. Only guys then, of course. Ladies never jousted.
2. In a series of letters to the editor, as shown above.

This used to be great fun and made all and sundry aware of the fact that truly scientific questions might have clear and unambiguous answers, indeed, but that it's not always easy to find them. Moreover, you should never just trust what somebody in authority tells you.
Alas! Those good old times are over. Scientists hardly fight anymore. It's too time consuming and to risky. Your opponent might be the guy (or gal) who referees your next paper or, worse, judges your proposal for money. Gone are the days when a professor was employed for live, had a budget that couldn't easily been cut and, best of all, had no real boss who could show him the light or else.

2002 J.D. **Verhoeven**, Genuine Damascus Steel: A type of banded microstructure in hypereutectoid steels" Steels Research 73, **2002** p. 347 - 55

2003 **J. D. Verhoeven**, Historical background of Damascus blades, (2003).

2004 J.D. **Verhoeven**, A.H. **Pendray** and W.E. Dauksch: "The Continuing Study of Damascus St from the Alwar Armory" J of Met. 56, No. 9 **2004** p. 17 - 20

Abstract: The authors published a paper in this journal in 19981 titled “The Key Role of Impurities in Ancient Damascus Steel Blades.” Because of the continued popularity of the on-line version of this paper,2 additional experiments were conducted on some three-century old Damascus bars. The results of those experiments are reported in this paper.

2007 John **Verhoeven**: "Pattern Formation in Wootz Damascus Steel Swords and Blades" India. J. of Histoy of Science, Vol 42.4 **2007** p. 559 -574

Abstract: Museum quality wootz Damascus Steel blades are famous for their beautiful surface patterns that are produced in the blades during the forging process of the wootz ingot. At an International meeting on wootz Damascus steel held in New York in 1985 it was agreed by the experts attending that the art of making these blades had been lost sometime in nineteenth century or before. Shortly after this time the author began a collaborative study with bladesmith Alfred Pendray to try to discover how to make ingots that could be forged into blades that would match both the surface patterns and the internal carbide banded microstructure of wootz Damascus steels. After carrying out extensive experiments over a period of around 10 years this work succeeded to the point where Pendray is now able to consistently make replicas of museum quality wootz Damascus blades that match both surface and internal structures. It was not until near the end of the study that the key factor in the formation of the surface pattern was discovered. It turned out to be the inclusion of vanadium impurities in the steel at amazingly low levels, as low as 0.004% by weight. This paper reviews the development of the collaborative research effort along with our analysis of how the low level of vanadium produces the surface patterns.

This paper essentially give an overview of Verhoeven's work concerning "Damascus" steel. It is all you need to read. This link provides a copy

J.D. **Verhoeven**: "Steel Metallurgy for Non-Metallurgists" Chapter 15, ASM International, Materials Park, OH **2007**.

Wow!!

The jousting isn't over yet. It looks like the Verhoeven - Pendray team leads, at least in numbers of publications. Wadsworth, on the other hand, cannot respond as much as he might want to because he is not (like me) a Professor at a University who can picks his own topics of interest but must put in some serious work for his money, too.
As far as I'm concerned, the tournament must go on because, to quote Verhoeven: "after reading these papers I thought it likely, based on my research experience that both might be incorrect". In other words: I still see some open points that are not clear to me. I will elaborate on this later.
Where does all this leave us? More precisely, where does all that leave innocent bystanders like you, who do not have a formal education as Materials Scientists plus years of experience? Exactly where all other tournaments leave you. Take a side (toss a coin in case of doubt), believe, and be enthusiastic about your team.
You don't need to be able to do what they can do. You do not even have to understand what they are doing, just like in football, politics or religion.

- But this is science after all. So who is right? Wadsworth or Verhoeven? Just wait (or read on here). Most important: don't blame the referee! Rather send him money. Maybe he can be bribed.

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[1] C.S. Smith: "A History of Metallography", Chapters 3 and 4, MIT Press, Cambridge MA (1988).