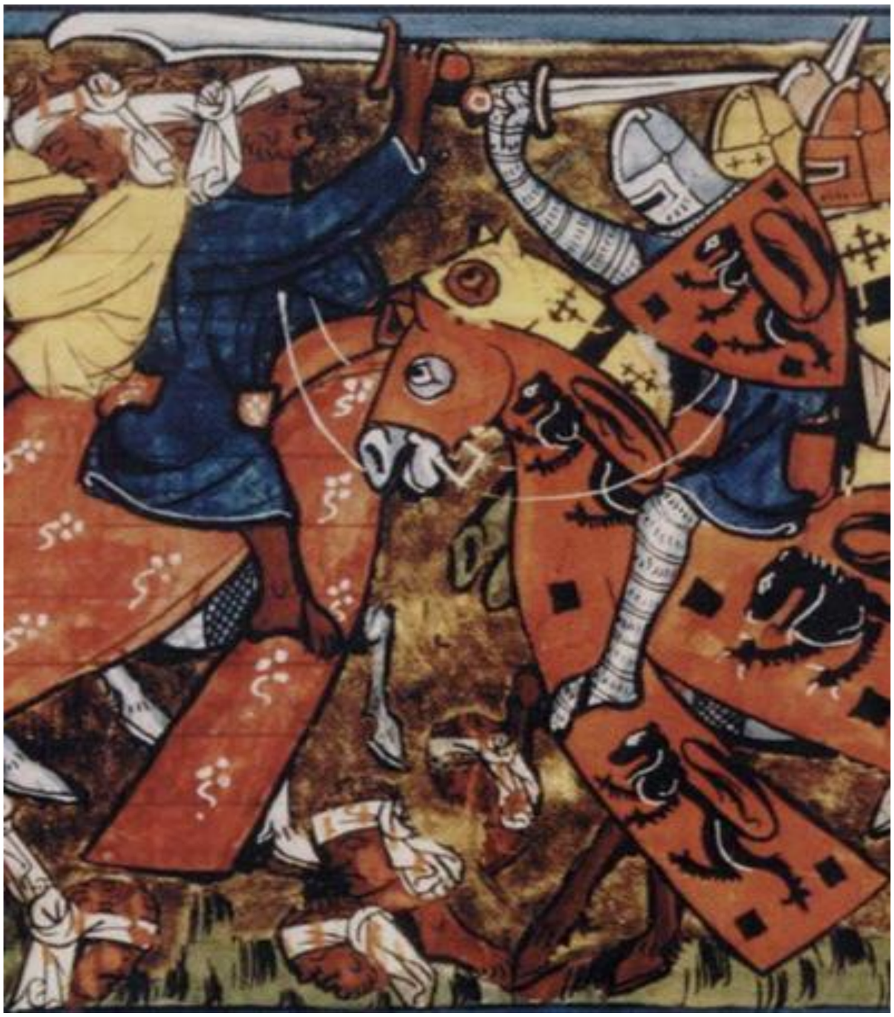
On Slaves and Silk Hankies
Seeking Truth in Damascus Steel



Stephen C. Alter, 2017
aka: Baron Hrodr-Navar Hakonsson, OP
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7.6.2 Composition/Research Paper

Much ink has been spilt by modern authors to extol the virtues of Damascus steel: *"[The} ideal combination of strength, hardness and elasticity*"[1], "*supersteel*"[2], and "*Acme of Mankind's Metallurgical Heritage* ."[3] At the same time one finds references to say that Damascus swords "*were stiff and even brittle*"[4], and:

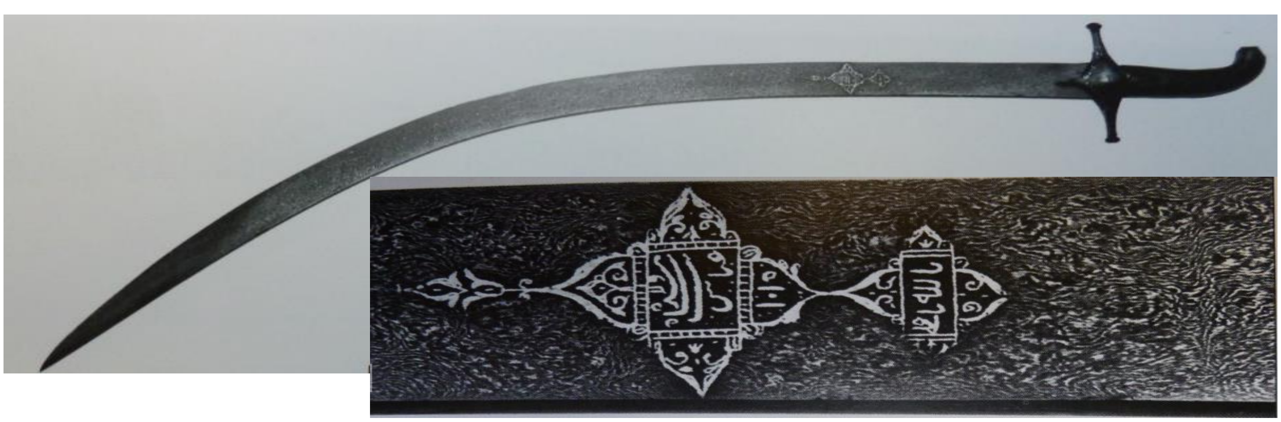
> [A]*ll the rank humbugs cluster about the legendary lore of Damascus steel like flies around carrion. So it becomes necessary to expose the fallacy … that this steel was the eighth wonder of the world* [5]

What are we to believe? Legend and modern literature say that Damascus swords were amazingly flexible, which is an extraordinary claim for ultrahigh carbon steel. Where is the proof? We are told that the Crusaders knew and feared these weapons, giving them the name "Damascus", but we are shown no references. Were newly forged Damascus swords really quenched in the blood of slaves? Did production of Damascus steel end when Timur carried off all the skilled workers? Modern authors say these things but don't back them up. One finds dozens of vendors today who advertise authentic Damascus steel blades for sale, is this the same material that the Crusaders and medieval Arabs knew? Finally, modern science has answered all the questions and recreated the lost art of forging Damascus steel. Or have they?

Bennet Bronson (curator of Asian antiquities at Chicago's Field Museum) wrote:

> *There can be few other themes in the history of technology that have attracted so much romantic, carefree speculation. The romance may have kept wootz* (Damascus steel) *and related topics alive among textbook writers, but speculation is so common that any attempt at real research is almost sure to bog down… as authors have gone on citing one another while ignoring original sources and as poorly documented and imaginative articles have continued to accumulate.* [6]

The question to be examined is: **What evidence exists to uncover the truth of Damascus Steel?**



What we know:

The hardness of steel increases with carbon content, as does brittleness. Increased hardness enables a tool or weapon to take a sharp edge, and keep that edge through use. While high carbon steels may excel at slicing things (and people) they generally come with a downside of being more breakable.

Early iron production was done in a simple bloomery furnace, which produced mostly low quality iron of less than 0.4 percent (%) carbon by weight, and small amounts of steel at 0.4 to 0.8 % carbon. Ultrahigh carbon steels (1.0 to 2.0 % carbon) were pretty much out of reach with this technology. The metal produced by the bloomery had another limitation, in that it was difficult to remove all of the non-metallic debris left over from the iron ore (called "slag"). Medieval smiths had ways of enriching small pieces of low quality iron with additional carbon to make limited quantities of steel, so European tools and weapons were commonly forged as a combination of a soft iron and hard steel.

A method was developed in India (possibly as early as 3rd C BCE[7]) that enabled conversion of bloomery iron into ultrahigh (1 to 2 %) carbon steel, and from this could be forged solid steel tools and weapons. This is called "crucible steel", and crucible steel made in India is typically called "Damascus Steel"[8] or "Wootz".[9] Crucible steel will have two distinct advantages over basic bloomery iron. 1) Its high carbon content will make it very hard by comparison, and 2) crucible steel is very clean. Iron melts in the crucible, enabling a clean separation between steel and slag. making a purer, stronger piece of steel. Damascus steel (crucible steel from India) had an additional feature in that it often developed a peculiar crystalline structure that resulted in the flowing damask pattern (known to Arabic sources as *water* or *jauhar*) that gave the finished product a beautiful appearance, making a sword that was a work of art in addition to being a deadly implement of war. It is generally accepted that Damascus steel was made in southern India, most notably in the region of modern Hyderabad, [10] and exported to the Middle East and China (where it was called *fulad* and *bin* respectively.) Damascus steel swords were made in many locations, al-Kindi identifies six different regions where swords were produced[11], and even says that swords were once made in Damascus in old times, but not in his day (c. 833-842). By the 19th C the best swords were made in Persia, but still using crucible steel imported from India.[12]

Swords made from 1 to 2% carbon steel would be expected to be harder than lower carbon steel (2 to 5 times harder[13]), and potential sharpness is related to hardness. Claims of the exceptional hardness and sharpness of Damascus steel are supported by medieval authors and 19th C scientists:

Bin iron, which is produced by the Western Barbarians, is especially fine ... It is so hard and sharp that it can cut gold and jade. (Li Shizhen, 10th C)[14]

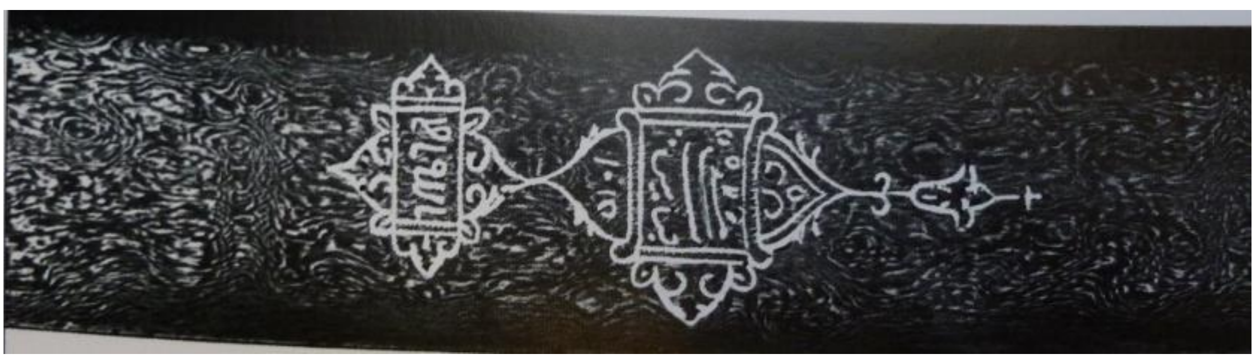
The Hindus excel in the manufacture of iron… They have also. workshops wherein are forged the most famous sabres in the world. …It is impossible to surpass the edge you get from Indian Steel.[15] (al-Edrisi, c. 1160)

[I]*ts extreme hardness* (is greater) *than the best English cast-steel.* [16] (James Stodart, 1818)

The *damask* or water patterns of forged Damascus steel are its most distinguishing visible feature. Medieval Arabic authors were effusive in their praise of the beauty and mystery of watered steel blades:

It has a water whose wavy streaks are glistening. It is like a pond over whose surface the wind is gliding. [17] **(**Aws bin-Hadjar, c. 540.)

In the perfect weapon, the extreme of sharpness lay hid, like poison in the fangs of a serpent; and the water of the blade looked like ants creeping on the surface of a diamond. [18] *(Hasan Nazaimi*, c. 1200)



The origin of the watered appearance of true Damascus blades has been debated for centuries. There are two major theories which can be thought of as "Nature vs Nurture". The "Nature" view says that the pattern is inherent in the steel cake that emerges from the crucible, and the smith is simply responsible for forging it. This view was expressed by al-Kindi[19] (842), Wilkinson (1837)[20] and most recently by John Verhoeven of Iowa State University. This theory holds that impurities in the iron ore cause steel with different carbon content to crystallize separately within the cooling crucible, and it is these crystals of different carbon content that we see as the light and dark patterns in the steel. Several impurities have been identified that will cause this effect,[21] plus there is support from experimental observations:

> *… I consider that it would be … impossible to forge a sword-blade out of some of these materials, when properly selected, without obtaining the true Damascus figure … These cakes of steel are evidently crystallized, and the future pattern of the sword-blades depends on the size and arrangement of the crystals, … it is not surprising that the proper kind of steel for this purpose should be so rare.*[22] (Henry Wilkinson, 1837)

The "Nurture" theory holds that the properties of Damascus steel are due to the skill and experience of the smith. This view maintains that any ultrahigh carbon steel could be given a damask pattern with proper treatment. Various techniques such as incomplete melting of the crucible contents, very slow cooling, and extensive forging at low temperatures have been suggested. This theory was supported by al-Biruni[23] (c. 1045), Anossoff[24] (1843), Harnecker (1924)[25] and Oleg Sherby of Stanford University[26]. This debate of Nature vs Nurture is ongoing, and will not be easily resolved.

The making of Damascus steel ceased in India around the year 1900. The Nature argument would say that the proper steel only came from specific regions, and when the appropriate ore deposits dried up the supply of Damascus steel ended. The Nurture theory would suggest that the disappearance of Damascus steel production was due to the fading and eventual loss of secret methods passed down through generations of artisans.

Having briefly discussed what Damascus steel "is", we can now discuss some claims and legends.

Legend #1: Damascus steel got its name from the Crusaders who named it after the city.

This legend is so often repeated that it has generated its own truth. Three noted authors have published extensive reviews of the available medieval sources, and have found no Western 10th to 13th C references to *Damascus steel*.[27] Thus there is no support to the legend that Crusaders coined the name.

Authors who casually state that the name was coined by Crusaders usually also add that the Crusaders feared the amazing weapons of their foes and that they felt their own weapons to be inferior. In fact there is no contemporary evidence that Crusaders were even aware of Indian steel as something different or remarkable aside from one tantalizing reference in the Arthurian legend of Sir Wigalois, written in the early 13th C. Sir Wigalois slays the dragon with a lance from *"Inner India, where there is a kind of steel* *that is red from the gold in it, and is so hard that it cuts stone like a twig.*"[28] There is speculation that the author himself may have been a Crusader knight[29] which could have given him first-hand experience with Indian steel. Al-Kindi[30] wrote of some Indian steel swords giving a reddish sheen, so the account of a weapon made "*of steel that is red"* may be a first-hand description of the real thing. There is nothing to indicate that the Crusaders feared or coveted the weapons of the Arabs. Indian and Arabic blades would have been optimized for use against lightly armored opponents, so thin hard swords of extreme sharpness were admired for their ability to cut through cloth and flesh.[31] The same attributes that excelled in traditional Eastern warfare may not have fared so well against the more heavily armored Crusaders. Chainmail, the ubiquitous armor of the Westerners, would have been particularly good defense against a weapon designed for slashing cuts.

The following quote is oft-repeated and said to be attributable to some unnamed Western Crusader[32]: "*[T]heir quality was such that one blow of a Kerman sabre would cleave an European helmet without turning the edge".*[33] These words are actually from the 16th C historian and cleric Paulus Jovius, well after the last Crusade and not a first-hand account.

There is a famous account where England's Richard I cleaves a steel mace with his sword, then Saladin responds by cleaving a silk veil with his Damascus blade. That epic meeting never happened, it is a work of fiction from *The Talisman* by Sir Walter Scott. Slicing a silk handkerchief is widely quoted in modern literature to prove the exceptional quality of the Damascus blade. What it really demonstrates is a sharp edge, which we already know is enabled by exceptional hardness.

Sachse[34] states that the root word *damas* means *water* in Arabic. Al-Assan finds the term *Damascus steel* in common usage in Syria by the 14th C.[35] Feuerbach[36] credits the earliest Western use of the term *Damascus steel* to the memoirs of a French traveler in 1432. Panseri [37] states that referring to the steel or swords as *Damascus* only became common usage in the West during the 18th and 19th C. In conclusion, there is no clear evidence of the origin of the term Damascus steel.

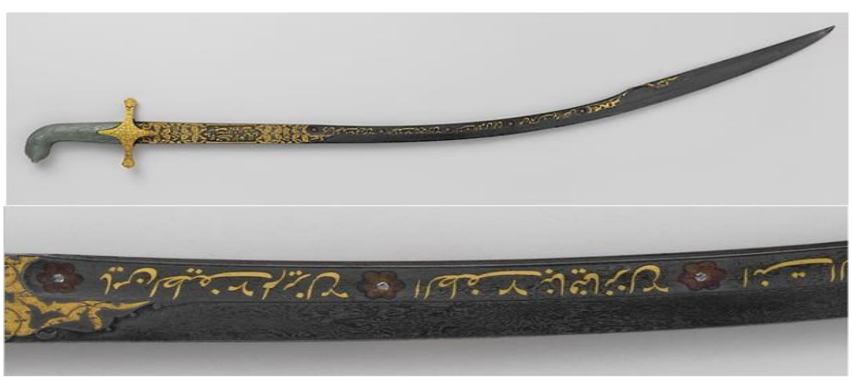
The word *wootz*, which is commonly used as synonymous with Damascus steel, was coined by the English scientist George Pearson in 1795[38], and is a Western corruption of the native Indian word.[39]

Legend #2: True Damascus steel is made from pattern-welding two or more types of steel.

Modern blade-making magazines and markets are full of beautiful "damascus" knives, made by folding strips of steel to create an attractive wavy pattern reminiscent of the water of a Wootz/Damascus blade. Swords much like these were indeed used in Rome[40], Islam[41], Scandinavia[42], and the Frankish Empire[43], but they do not represent the historical material known as Damascus steel (see endnote 1). Blades made in this way are more appropriately called "pattern-welded"[44] to distinguish them from true Wootz/ Damascus swords made from a cake of crucible steel.

The modern use of the word "damascus" to refer to pattern-welded blades can be traced to the American bladesmith, Bill Moran. In 1973 Moran exhibited several pattern-welded knives at the 1973 Knifemakers Guild show in Kansas City, MO, calling them "damascus"[45] The name stuck, and today an entire industry is built around the link of ancient Damascus steel to modern pattern-welding techniques. Popular publications and commercial websites gush poetically over the mystical history of Damascus steel, routinely confusing references to Wootz, crucible steel and pattern welding, and claim that their blades represent the lost secrets of ancient Damascus steel. It is unfortunate that the same word is used to describe two very different processes, but this is only one of the riddles in the literature.

There is historical precedent for this confusion. Lord Egerton of Tatton, (1880) collector and cataloguer of the India Museum collection, describes in great detail several methods much like modern pattern-welding that were used to make gun barrels. In his catalogue he refers to the guns as "Damascus", while he refers to watered steel blades as "Damascus steel". He also notes that in some regions knife blades were made using methods similar to the making of gun barrels, and that another way to imitate *jauhar* (water) was by etching lines onto the blade using a corrosive liquid. [46]



Legend #3: Damascus swords are amazingly flexible

"*bent until the point touched the hilt*"[47],"*swords can be bent to about 90º*"[48], "*bent around the body of a man*"[49] These are just a sample of what you will find in both the popular and the scientific literature. This is the current expression of an old legend that Damascus steel swords were not only extremely hard and sharp, but also amazingly flexible. The earliest mention I have found of this legend is from the memoirs of a British soldier, showing that that the flexibility legend was well established by the 1840s.

> *We read an absurd account of a Damascus blade appertaining to the celebrated Kaliph Haroon ool Rusheed, so elastic that the monarch usually carried it coiled up like a watch-spring in his turban.*
>
> *I confess I have never met with an elastic Damascus blade … A blade that was in my possession … exhibited the most exquisite water, and an edge that I have never seen equaled. But … it was unelastic. Nothing that I have seen approaches in beauty to these blades, or in firmness and keenness of edge.*[50] (Capt. James Abbott, 1843)

Hardness in a 1 to 2% carbon steel blade is expected, but exceptional toughness (i.e. resistance to breaking, also called flexibility or elasticity) is an extraordinary claim as brittleness will tend to increase as the carbon content of steel increases. It is this mythical combination of hardness and flexibility that has fixed Damascus steel in the popular imagination as a "supersteel of the ancients"[51].

Slicing a silk hanky is a fairly safe parlor trick, and there are other safe ways to test hardness in a laboratory, but measuring toughness or flexibility requires bending to the breaking point. Few modern collectors would be willing to have their priceless objects destroyed for the sake of science, so the actual data on flexibility of Damascus swords is very slim. In one study conducted in the 1920s, four Damascus and two European swords were tested to breaking, and both European swords were shown to be more flexible than the Damascus steel swords.[52] Another test[53] showed that Damascus steel blades of 850-900 mm could bend 10-15 mm, or approximately 2 degrees. This hardly qualifies as remarkable flexibility, and certainly does not justify claims of swords bent to 90 degrees or being wrapped around the body of a man, as one finds in some modern literature. Since we are unlikely to convince enough donors to surrender their vintage weapons to test flexibility in a laboratory setting, we should not expect to get any better data. Medieval Arabic authors provide first-hand accounts of the properties of Damascus steel.

It rarely happens that Yemeni swords are free from veins … where there occurs splitting and separation, and it may break at that place.[54] (al-Kindi ,833-842)

The cutting power in the watering ... is a result of its hardness, but breaking and crumbling are also associated with it.[55] (al-Biruni, c. 1045)

Also, the Andalusian poet Idrıs al-Yamani (late 10th C.) described shields made of hardened leather that were capable of withstanding and even cracking the purest *fulad* swords, because these were more fragile than other blades.[56]

Thus it appears that among medieval Arabic sources, Damascus swords were not seen as wonderfully flexible as modern authors are wont to state. In fact their brittleness seems to have been well known. This is underscored by comments on the performance of Damascus blades in cold weather:

Ancient swords are divided into three categories: the first and most excellent is the Yemeni …Its use on a cold day is feared lest it breaks.[57] (al-Kindi ,833-842)

The Russians … make the edges of their swords from hard iron and the middle channels from soft iron so that they might be firmer when striking and less likely to break, for (crucible) *steel will not stand the coldness of their winters and breaks with a single blow.*[58] (al-Biruni, c. 1045)

[T]*he two edges of the* (Frankish) *saber are of steel while the blade itself is of iron … The Arabs claim that the fabrication of these is the work of Genies. They are more resistant to the blows one gives with them even during cold weather, while the Indian saber often breaks when the weather is cold…*[59] (Ibn Hudhayl 14th C.)

These observations suggest that Damascus blades were *cold-short*, which is a tendency for steel to fracture when cold, usually attributed to levels of phosphorus (P) at 0.07% or higher.[60] Bronson[61] gives the elemental analysis of several pieces of Damascus steel. Of eleven samples that provided P content, eight had P above 0.07%, so it is likely that cold-shortness was a problem with Damascus blades.

Nor is the claim of exceptional flexibility of Damascus swords supported by later Western sources. Shipping manifests show that England did a brisk trade in the 16th and 17th C bringing blades into India (the home of Damascus steel), even selling Western swords to wealthy consumers who could afford the best.[62] Western travelers in India wrote about the native swords:

Their swords are made crooked like a falchion, very sharp but for want of skill in those that temper them, will break rather than bend; and therefore we often sell our sword blades at high prices that will bow and become straight again.[63] (Edward Terry, c. 1616)

> *The swords made by the Indians are very brittle, but the English furnish them with good ones brought from England*.[64] (Jean de Thevenot, 1687)

> *The Maharattas … seldom encumber themselves with anything but a pair of swords; one of a hard temper, consequently brittle and very sharp, called 'serye'; the other more tough and less sharp named 'asseel'.*[65] (Sir Charles W. Malet, 1795)

William Forbes-Mitchell (1895), a British veteran of the war in India, wrote of his first-hand experience:

> *The real Damascus blade that we have all read about, but so few have seen, is as rigid as cast-iron, without any spring whatever. The sword-blade which bends is neither good for cut nor thrust, even in the hands of the most expert and powerful swordsman. … When the fight was over I examined that sword. It was of ordinary weight, well-balanced, curved about a quarter-circle, as sharp as the sharpest razor, and the blade as rigid as cast-iron. Now, my experience is that none of our English swords could have cut like this one.*[66]

Lord Edgerton of Tatton (1880) describes several Arab swords in his collection, and of the better ones he says "*The blade is generally flexible, in many cases of Spanish, Italian or German origin*" and *"The Indian steel, however, has never equaled the European in toughness and flexibility."* saying that it was common to fit Western blades with an Arabic pommel and crosspiece. [67]

Thus we have no source to support a claim of exceptional flexibility for Damascus swords. The only scientific data, as well as a number of first-hand accounts, support the view that Damascus (Indian steel) swords were indeed stiff and brittle by Western standards, which should be considered normal for ultra-high carbon steel.

Modern authors often state that Damascus steel is "ductile", [68] using this single word to imply "tough and flexibile" (see previous discussion) without getting into the details, or dealing with the embarrassing fact that the historical record shows that it was neither. Ductility is defined as "*the ability of a material to deform plastically before fracturing*"[69], and is most easily visualized in making wire. A hot bar of ductile metal can be pulled into a very small diameter wire of great length without breaking, and the wire retains its new shape. Damascus steel was drawn into wire for musical instruments[70], so there is proof that it was ductile. But other steels have been used to make wire, so they too are ductile. One might say that one material is more ductile (or brittle) than another, or that it gives a certain measurement on a scale of ductility. Simply stating that some material is ductile has no real significance without knowing HOW ductile it is. The earlier discussion presented several first-hand observations that Damascus (Indian steel) swords were brittle and inflexible as compared to their Western counterparts. To simply say that Damascus steel was ductile with no comparative reference may be true, but is misleading.

Legend #4 The technology was lost in the 14th C. when Timur carried off the metalworkers.

There may be some truth to this legend. Three biographies agree that after the sack of Delhi, Timur (aka Tamerlane) transported skilled craftsmen of all kinds from India to his capital of Samarkand in Persia.[71] However, it is also documented that Damascus swords continued to be made in India into the 19th C.[72] and Damascus steel was made as late as 1900.[73] So Timur's actions, if factual, may have relocated knowledge, but did not cause the technology to be lost. Fraser[74] and Egerton[75] suggest that Timur's relocation of metalworkers to Samarkand (in 1398) is responsible for Persia becoming the leading region for manufacture of Damascus swords by the 19th C.

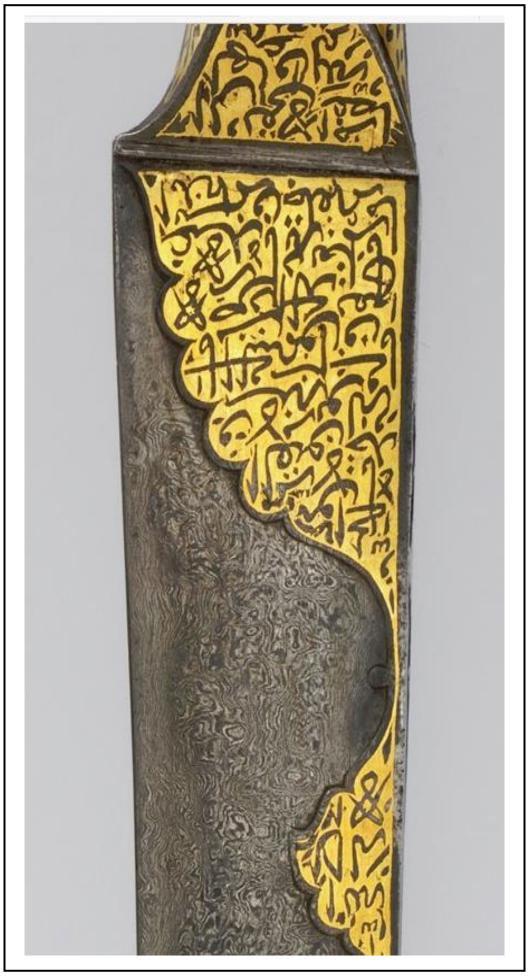
Following the Sepoy Mutiny and Indian Rebellion of 1857-9, the English government enacted new laws to regain control of its Indian colony. Damascus swords, which had become symbols of Indian cultural identity,[76] were collected and destroyed, and the making of new swords was restricted. In 1866, the English prohibited Indian steel making, ostensibly to preserve the remaining forests.[77] Perhaps, but this was more likely a tactic of the British Empire to remove a source of national pride, and to increase its colony's dependence upon England for materials. The following quotes indicate that the prohibitions were having the desired effect.

> *Nowhere within British territory is indigenous steel procurable. ... It is needless to add that the operation of the Arms Act has done much to diminish the number of weapons; but a few of the best makers who still remember the Sikh days or have learned from the armourers of those times, hold licenses and are able to ply their trade.* [78], (Baden-Powell, 1868)

If disappearance of the technology was due to loss of skilled workers and knowledge, then these actions by the British government probably had a greater impact than anything done by Timur in the 14th C.

Legend #5: Damascus steel is a defined material with consistent characteristics.

A discussion of the truth of Damascus steel presumes that there is one identifiable definition of



Damascus steel, and even this is elusive. Wilkinson[79] described a study in which he obtained two ingots of Indian crucible steel from different regions. One sample "*furnished excellent steel, …* (and) *exhibited the Damascus figure both in the cake itself and when drawn out and forged into a bar*", while the other "*gave only slight indications of a pattern, … and steel inferior in quality.*"

Bronson[80], in reviewing 18th and 19th C Western publications, and Khorasani[81] citing Persian manuscripts, both identified five regional variations of steel manufacture that produce metals with different properties and different watering. Panseri[82] says that there may be as many as 25 different types of Damascus steel. Thus it may not be appropriate to speak of one commodity called *Indian* or *Damascus* steel.

Legend #6: Ancient smiths used wacky superstitious methods to quench Damascus swords.

There are modern references which claim that ancient smiths quenched their Damascus blades in dragon's blood,[83] the urine of a red-haired boy, or urine of a three year old goat fed only ferns.[84] It is not hard to uncover that the use of the urine of a red-haired boy and a three year old goat are attributable to the German monk Theophilus Presbyter[85] (c. 1100). The instructions for using dragon's blood also originated in medieval Germany, in the form of a pamphlet called *Von Stahel und Eisen* (On Steel and Iron) first printed in 1532.[86] All three quotes refer to the general quenching of steel items, but originated in Germany so they have nothing at all to do with Damascus steel.

Medieval Islamic references to quenching of Damascus swords say that water was used.[87] The hot steel was said to "*drink water*" and improperly quenched blades were said to be "*dry*"[88], implying a belief that the act of quenching caused water to be incorporated into the steel. One variation was to quench only the edges of the blade, while the center remained unquenched. This would have had the effect of further hardening the striking surfaces, leaving the unhardened center of the blade more pliable.

> "*It goes to water, but only the edges drink as much as they wish. Next to them there are gazelles that quench their thirst with grass."*[89] (al-Mutanabbi, c. 950)

Verhoeven's group at Iowa State analyzed several authentic Damascus blades and concluded that they were not quenched at all, but slowly cooled.[90] There is a myth that the newly-forged blade was removed from the fire and given to a horseman who sped away with the red-hot blade held high in the air.[91] This would provide air cooling to the hot metal, but one would think that this process would be difficult to control and would result in a large number of work-related injuries. While a very romantic image, it does not sound very practical, and I have seen no justification for this legend. At the opposite end of the romantic/practical spectrum is an account by al-Biruni (c. 1045) who describes a technique for cooling hot steel blades by slathering them with cow dung.[92]

The wackiest legend of all involves a lurid description of an ancient ritual where the curved blade is sharpened and thrust into the fire "*while reciting the prayer to the god Bal-Hal until the steel be the color of the red of the rising sun when he comes up over the desert toward the East"* and quenched by thrusting "*six times through the most fleshy portion of the slave's back and thighs*", after which the slave's head is severed "*and the blade may be bent around the body of a man and break not*."

This story is widely reprinted in modern literature, and if it is referenced at all, the author invariably points to another secondary reference. Finding an original source has required a bit of sleuthing. Thanks to Dr. Helmut Föll[93] (University of Kiel, ret) we can trace this legend to an obscure article on page 28 of the Chicago Tribune, Nov. 4, 1894.[94] The story, entitled "*Tempering Damascus Blades*", dateline "*Berlin Tagblatt*", says that a "*Prof. von Eulenspiegel*" found this scroll "*among the ruins of ancient Tyre"*. The newspaper Berliner Tagblatt is searchable on-line, but there is no reference to a "Prof. von Eulenspiegel" in any issue dated 1894 or earlier.[95] Thus we cannot be certain if this tale began with the Chicago Tribune, or if it goes farther back in time. We do know, however, that "Eulenspiegel" is the name of the legendary prankster of medieval Germany,[96] which clearly identifies the article as a hoax.

So how did this fanciful tale become part of the scientific literature? After appearing in the Chicago

Tribune, the story resurfaces Dec. 27, 1894 in the Western Morning News (Plymouth, England). Then in 1895 it was published by the prestigious British Iron and Steel Institute[97], in a section of their journal reporting news items from around the world. So it was not offered as serious research, but simply as an interesting news item. This, however, was enough to legitimize the story. It appears again in a scientific journal in 1940[98] and a textbook in1948[99] by which time it was established as fact.

One can find references which state that Damascus steel blades could be bent around the body of a man, even though there is no documentable support for claims of such flexibility. Due to the similarity of the wording, this claim may also have originated with the slave legend. Congratulations to the unnamed author whose joke has persisted for over a century!

Legend #7: "Superplasticity" and the modern rediscovery of an ancient process

Oleg Sherby & Jeffery Wadsworth at Stanford University (champions of the "Nurture" hypothesis) have found that ultrahigh carbon steel (UHCS) can be mechanically worked to a fine granular structure, and that this material shows "superplasticity" at elevated temperatures, defined as:

the condition in which certain crystalline materials can be stretched 1000 percent and more.[100]

they behave like molasses or semimolten glass at temperatures of 600 to 800 degrees C.[101]

This is important work, and a real advancement in materials science. Unfortunately, the same authors go on to compare their laboratory results to "*general statements*"[102] made about historical Damascus steel, in particular its reputed toughness and flexibility. These papers have encouraged a new round of articles touting the "superplasticity" of Damascus steel. While their work on UHCS represents cutting-edge materials science, their claims regarding Damascus steel are on shaky ground. Sherby & Wadsworth do not provide any new references or data to prove exceptional toughness or flexibility of historic Damascus steel. Their claim to have reproduced Damascus steel is debatable as they have not demonstrated that historic Damascus steel actually had the features they claim to have reproduced.

The authors used modern equipment to create their superplastic UHCS, and thereby "*rediscovered the lost art of Damascus steelmaking.*"[103] One wonders if they have indeed recreated an ancient process, or simply created a new one. John Verhoeven's team at Iowa State University reproduced the method of

Sherby & Wadsworth and concluded that it is "*probably not the technique used by ancient blacksmiths to produce the Damask pattern in their blades.*"[104] Of course, Sherby & Wadsworth published a rebuttal,[105] and so the debate continues.

In the meantime, the Verhoeven group (champions of the "Nature" hypothesis) also claimed to reproduce Damascus steel,[106] however their claim is fundamentally different. While Sherby & Wadsworth focused on legends of toughness and flexibility, Verhoeven's group limits their claim to reproduction of the damask pattern (water) of genuine Damascus steel. Furthermore, the Verhoeven group has used trace contaminants found in Indian steel artifacts and hand-forging methods to produce their modern version.

It is not my intention to resolve this dispute here. The point is that modern authors who quote these sources and declare that one or the other has rediscovered the lost secrets of the ancients are not telling the whole story. Such statements give the mistaken impression that we now know everything there is to know on the subject.

Conclusion:

What evidence exists to uncover the truth of Damascus Steel?

(1) Damascus steel got its name from the Crusaders: NOT supported by evidence. (2) Ancient Damascus steel was made from pattern-welding: NO, two completely different methods with confusing names. (3) Damascus swords are amazingly flexible: NOT supported by evidence. (4) Timur carried off all the skilled metalworkers: Possibly supported by evidence, but Timur did not cause disappearance of the technology. (5) Damascus steel is a single defined material: NOT supported by evidence. (6) Wacky superstitious methods of quenching: NOT supported by evidence, although the one method using cow dung is the least fanciful so has the best chance of being authentic. (7) "Superplasticity" and the modern rediscovery of an ancient process: Debatable.

In closing, Damascus (Indian crucible) steel was the highest quality steel available in the medieval world. It contained a higher carbon content than anything available in the west, and would have been relatively free of slag, making a stronger, more homogeneous piece of steel. Swords made from this steel were remarkably hard and sharp, but they also had limitations.

By now it should be clear that there is much that we do not know about Damascus steel. Even the name itself is misleading, as it did not come from the city of Damascus. Historical sources tell us that there were many types of crucible steel available. It does appear to be correct that much of this crucible steel came from India in medieval times, although there is evidence that it was also produced in Central Asia[107], Iran.[108], and Moorish Spain.[109] In fact, Craddock[110] and Williams[111] suggest that the fame and legend of watered Wootz/Damascus steel has overshadowed a larger trade in ordinary crucible steel, and that the true watered Damascus may only have been a small specialty portion of the total output. If one looks only at Indian steel, there were several regions where it was produced, and the product varied by region. Even the most obvious indicator of Damascus steel objects, the visible damask, is not totally reliable. Some blades made from Indian crucible steel had no damask. Was this due to Nature or Nurture? Should Indian crucible steel with no damask still be called Damascus steel? The use of a single term to cover all of the regional and physical variability compounds the confusion when trying to study the subject.

In researching this topic I have sought to verify the sources of many oft-cited quotations, and uncover additional information not commonly seen in the literature to shed light on the true nature of Damascus steel. I have searched for reports documenting first-hand experience with Damascus steel, or the genesis of some of its legends, to get the true story unadorned by hearsay and retelling. What has emerged is a fascinating picture of not only the historical Damascus steel, but also of the modern literature (and modern science) being misled by legend, hearsay and poor scholarship.

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