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One problem and three solutions: The steel of the European, Indo-Persian and Japanese swords compared.
Part 2- Indo-Persian swords and *wootz* steel

Francisco A. B. Coutinho

School of Medicine. University of Sao Paulo

Av. Dr. Arnaldo, 455 São Paulo – SP 01246-903 Brasil
coutinho@dim.fm.usp.br

This year, the Brazilians, who are Japanese descendents living in Brazil, are commemorating the first centenary of the arrival of the first ship with 800 of them from Japan. This series of articles is dedicated to this group, who, although few in numbers, have made an enormous contribution to their adopted society.

In the first article of this series it was established that if European smiths increase the amount of carbon in the steel, the **cementite (iron-carbide)** forms a network throughout the **ferrite** background that makes the sword very brittle. Accordingly, the European swordsmiths gave up making high carbon blades.

Nevertheless, the Indo-Persian swordsmiths did succeed in making swords with a high carbon content that were not at all brittle. Japanese swordsmiths, as we shall see in the next article in this series were also successful. The secret of the Indo-Persian swords was to break the **cemetite** network into bands of spheroidal particles. The manner in which this is accomplished is the substance of several competing theories. According to one reference [1], the secret was that they hammered their blades at fairly low temperatures and this permitted them to break down the **cementite** network. The forging of steels in Europe, as we have seen, was done at a fairly high temperature when the color of the steel was white, that is, at around 1200 ºC; however the Indo-Persian swordsmiths forged their blades when the color of the metal was between cherry (850 ºC) and blood red (650 ºC). To forge at such low temperatures is apparently very difficult. However, if you try to forge high carbon steel at higher temperatures the steel would crumble under the hammer [1]. This is why European swordsmiths failed to make blades with high carbon content. In fact, forging at a low temperature has the effect of breaking the continuous **cementite** network which makes high carbon blades brittle, into spheroidal particles. The **carbide** particles still serve the function of strengthening the steel but since they do not form a continuous network, the resulting blade is not brittle.

Reference [1] has photographs of the network of **cemetite** and also of the spheroidal particles that result from hammering the metal at low temperatures. The process is show in the Figure 1 below.

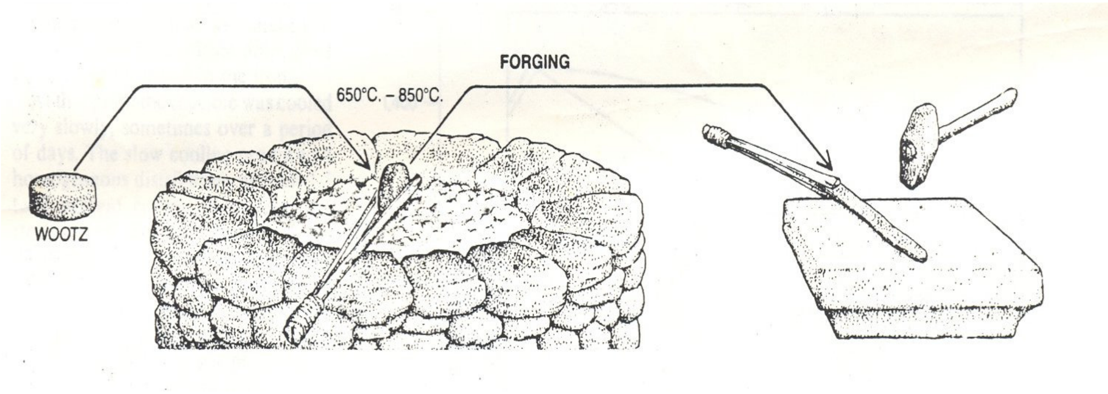

Figure 1

Figure 1 shows schematically the manufacture of an Indo-Persian sword.

The process of breaking the **cementite** network into spheroidal particles is undoubtedly the secret of the Indo-Persian swords. In addition to the method suggested by Jeffrey Wadsworth et al. [1], another article by John D. Verhoeven [2] suggests a different procedure. In any case, there are other ways of breaking the **cemetite** network. The important point is to break it so that there are bands of spheroidal **cemetite.**

Figure 2 below shows the next step. It is necessary to heat the sword and then quench it so that we have **bainite** and, because the carbon content is high, a great deal more **martensite.**

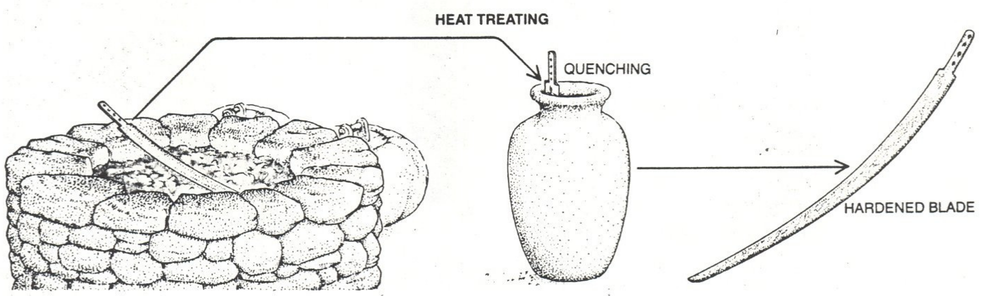

Figure 2

Figure 2 shows schematically the hardening process of an Indo-Persian sword.

The swordsmith would have to heat the blade up to about 730 ºC and then quench it. If the blade was heated to above 1000 ºC the **cementite** network, which the swordsmith worked so hard to break into spheroidal particles, would dissolve back into **austenite**. Then, in the process of cooling down, at around 800 ºC, it would again form the coarse network of **cemetite** resulting in a sword that would be too brittle. In summary, the Indo-Persian process can be described as follows. In this clever and no doubt very laborious fashion, the blade is forged at a low temperature, then heated and quenched, taking special care not to heat the blade too much.

The resulting sword, when polished and etched would show in its surface the pattern known as *Damascus* or *Damask* or *watering*. The aspect of the watering depends on how the blade was forged. Figure 3 below, taken from an article by Kapp [5], shows two ways of forging a blade. The first way, would result in a pattern which, in Japanese blades, is known as *masame* and in Indo-Persian swords as *sham.* The second method would result in a pattern which in Japanese swords is known as *itame* and as *wootz* in Indo-Persian blades. Sometimes, during the forging process, the Indo-Persian swordsmith would carve grooves across the blade and the result would be what is called the *Mohamed ladder* pattern.

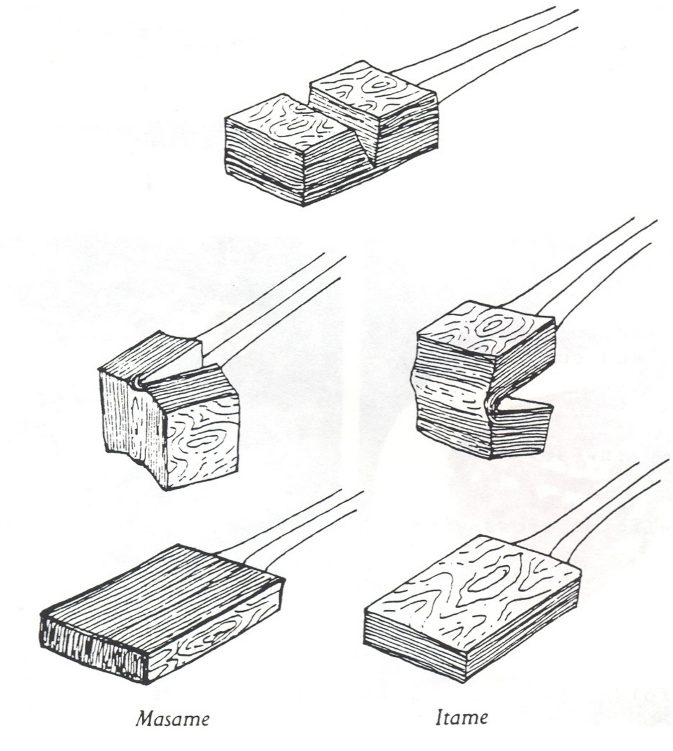

Figure 3

Figure 3 shows the two basic patterns that can be created - *masame* or *itame* in Japanese blades or their equivalent *shan* or *wootz* in Indo-Persian blades from Kapp [5]

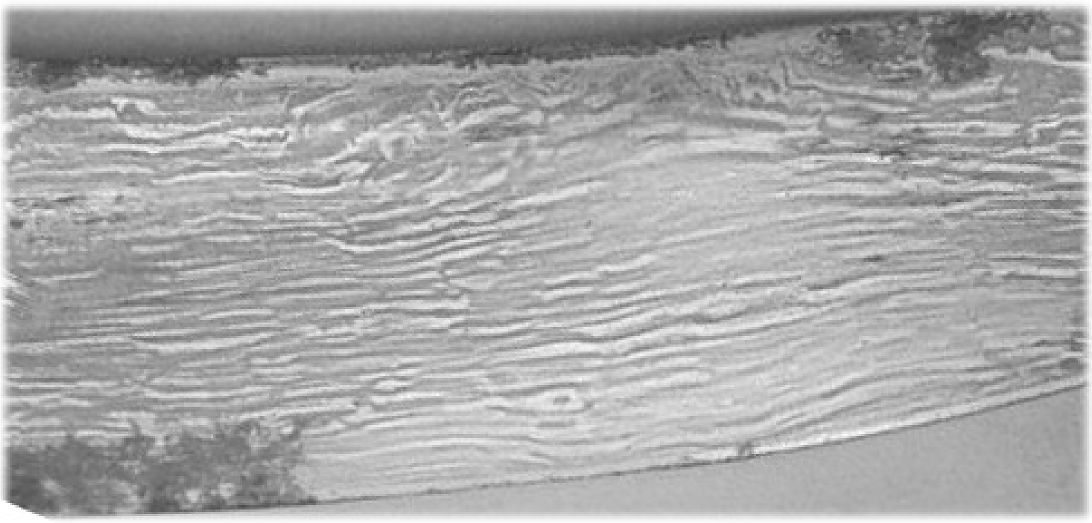

Figure 4a

Figure 4a shows the *sham* pattern without a *Mohamed ladder*.

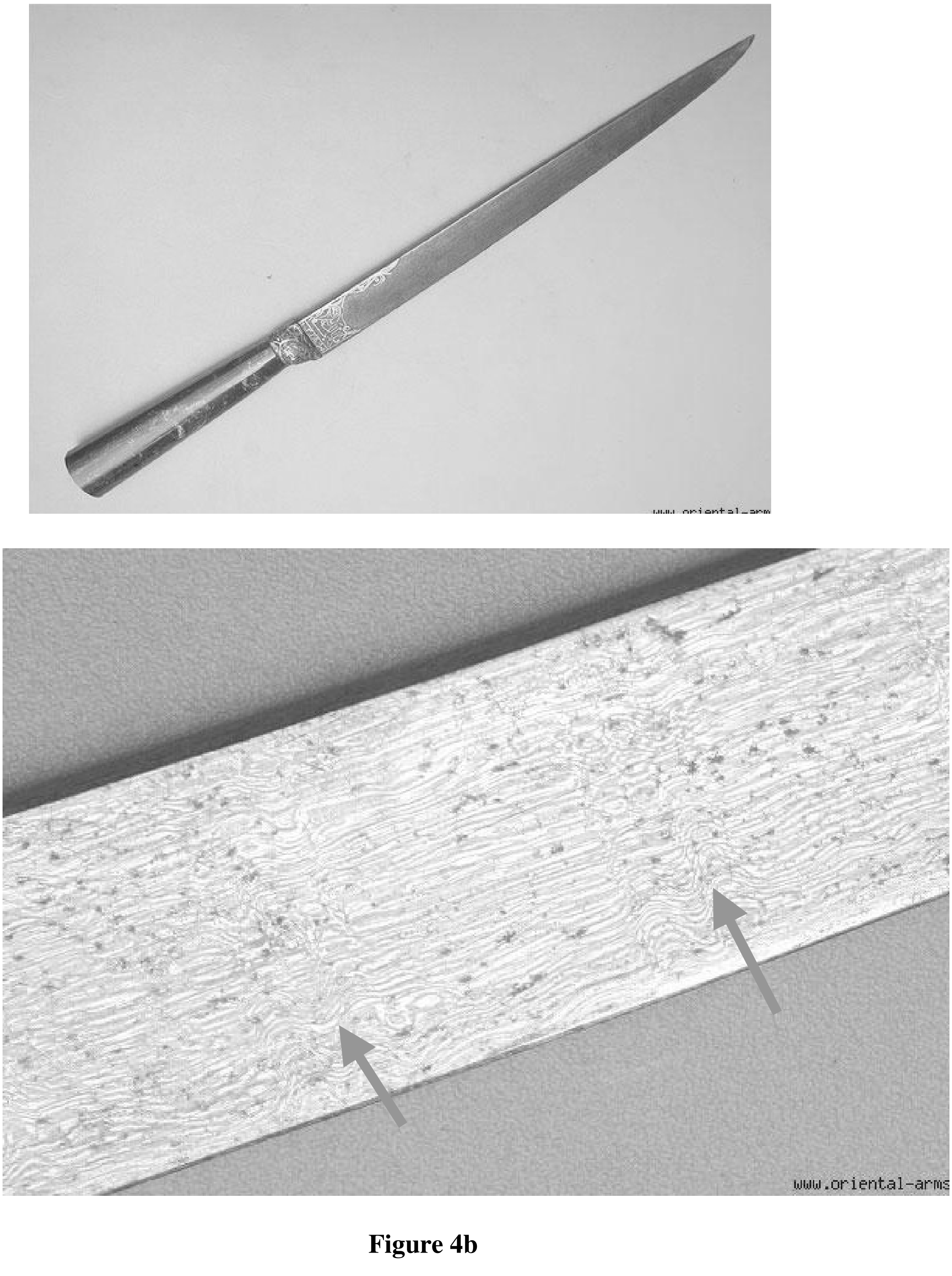

Figure 4b

Figure 4b shows the *sham* pattern with the *Mohamed ladder.* The pattern is shown with small arrows.

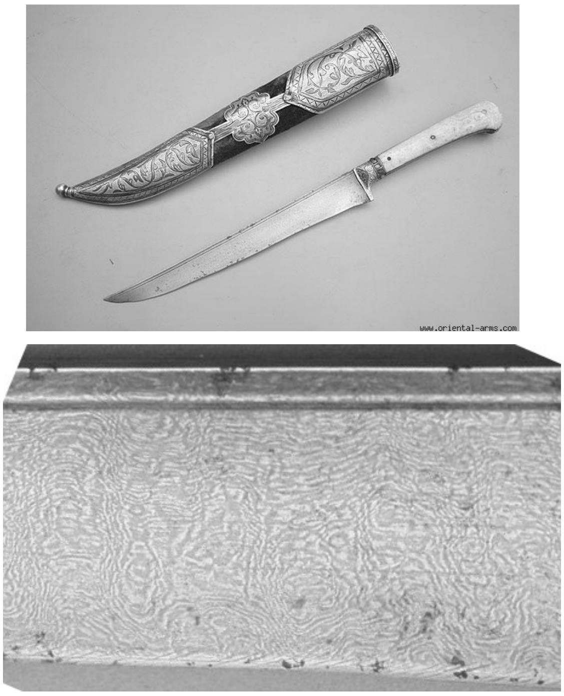

Figure 5a

Figure 5a shows the *wootz* pattern without a *Mohamed ladder*.

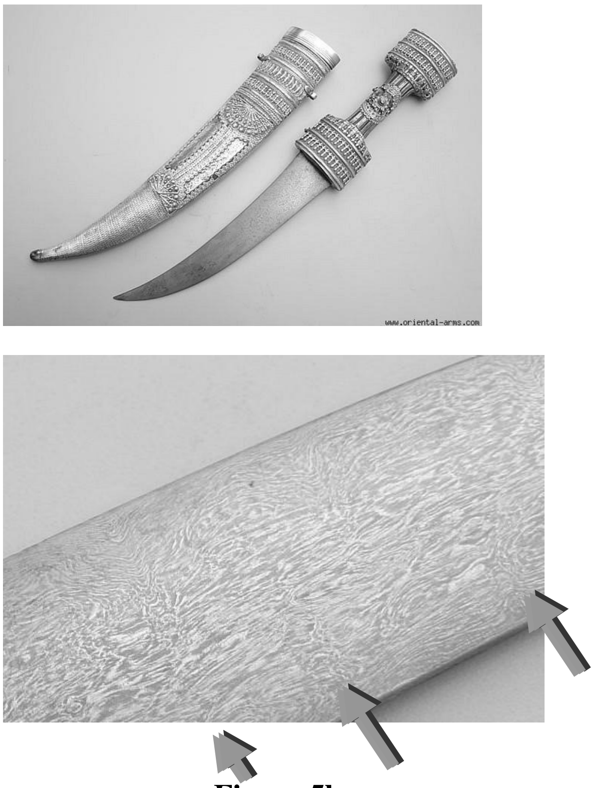

Figure 5b

Figure 5b shows the *wootz* pattern with a *Mohamed ladder*. (Note the arrows.)

The Damascus pattern is an incredible feat of metallurgy. The whitish areas of the Damascus are **cementite (iron carbide)** and the dark background is iron with considerably less carbon (**ferrite).** The patterns are very beautiful; the swords are very sharp and tough. However are they the same as the *hada* seen in the Japanese swords? Note that the whitish lines and the dark background lines are thicker than **most** of the lines we see in the *hada.* A clarification of *wootz* steel follows.

It is known that when the process of forging is very thorough, the *wootz* pattern will disappear [1]. Moreover, from a modern scientific view, swords so "over forged" would be much better than the swords with a very clear pattern. With this in mind the question arises, "Why did the Indo-Persians forge in such way as to leave such a clear pattern visible?" One possible reason, advocated by Jeffrey Wadsworth et al. [1], is that the *Damascus* is, to potential buyers, a proof that they are buying a blade properly-forged with high carbon content.

The Japanese swordsmiths forged steel very thoroughly. In the words of Jeffrey Wadsworth et al. [3, 4], "The Japanese sword's *uagane* is an ultrahigh carbon steel (typically 1.3% C [carbon]) prepared from *tamahagane*, a product of the reduction process using iron ore, sand and charcoal. *Tamahagane* contained about 1.9% C [carbon], a level which is too high for optimum mechanical properties. It was consequently forged, folded on itself, and solid state welded by further forging. This process was repeated more than 15 times to form appropriate shape". Later the authors state "the end product is an *uagane* steel with excellent mechanical properties because the carbon content is relatively low (about 1.35% C [carbon]) and distributed uniformly in a fine grained matrix. No visible pattern welded structure is obtained." Stay tuned for the next article on *hada* – the surface grain of Japanese blades. Note that the *hada* lines are thinner than the black and white lines we see in the Indo-Persian swords. Note also, that according to Jeffrey Wadsworth et al [3, 4] "it is sometimes possible to see true Damascus watering on a Japanese sword." In the next article we shall also consider that possibility.

Sham and ordinary *wootz* are not the only type of pattern seen in Indo-Persian swords. Another pattern known as **mechanical damask** also appears. Drilling holes and grooves in the steel before forging makes mechanical Damask. Swords with **true** Damascus (a consequence of the different colors assumed by **cementite** and **ferrite** under etching with acid) do not have mechanical Damascus except for the *Mohamed Ladder* we have seen above. The way of creating mechanical Damascus is illustrated in an article by F. Karel Wiest [6] and in an article by Willis Hawley [7]. Perhaps this provides a hint to the differences between *hada* and *wootz.*

Mechanical Damascus is shown in Figure 6 below.

Figure 6

Figure 6 shows mechanical Damascus. Contrast this to *sham* and *wootz.*

The literature on Indo-Persian blades is not as extensive as the literature on Japanese swords. Two books [8, 9] and one article [6] listed below provide more information on Indo-Persian blades.

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