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ON THE QUESTION OF POSSIBLE TRANSFER OF STEEL TECHNOLOGY FROM INDIA TO EUROPE THROUGH THE MUSLIM MIDDLE EAST

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The word *Wootz* appeared in Europe at the end of the 18th century, one century after the first description by a French traveller of Indian crucible steel ingots. Such steel had been in use in Arab countries since the 9th century and it is surprising that, apparently, no direct knowledge of these techniques was transmitted from East to West during the two centuries of the Crusades and the eight centuries of domination upon Spain by the Saracens. An analysis of this question is proposed here, in four complementary directions: (i) what kind of technical knowledge on crucible steel properties – and when- was transferred from India to Europe, through the Near East countries? (ii) what kind of knowledge upon the existence of the oriental steel can be found in the non technical literature, epic poems and old chronicles? (iii) how and where to find other historical sources? (iv) why was the transfer apparently delayed until the 18th-19th century, and does this appearance dissimulate another reality? Contrarily to the Arab publications, which were in great number but unknown from Europeans until the 18th century, the Western technical testimonies are very scarce. The main pieces of testimony available today have been gathered in the present paper, those with a technical content and those coming from epic literature and old chronicles. An historical analysis of the European civilisation is proposed to describe the barrier established between the Western and Eastern worlds during ten centuries.

Key words: Al-Andalus, *Azzimina*, Carolingian, Chardis, Crucible steel, Crusades, Damascus, Karalough, Song of Roland, Tavernier, Wootz.

INTRODUCTION

The question of technology transfer discussed here concerns the history of Wootz crucible steel and/or Damascus steel, and the apparent lack of

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interest of Western countries face to the steel technology of the Eastern ones, India, Persia and Muslim Near East, during one thousand years.

The development of crucible steel (i.e. melted steel) is an important question from a technological and historical point of view. In Europe, the first crucible steel was produced at Sheffield (UK) by Huntsman in 1740. In France, the technology was imported by Jackson to Saint-Etienne in 1816[1]. However, one thousand years ago, crucible steel preparation was already described by Arab scientists [1, 2, 3, 4] and this technique was present on a large territory extending from India to the Near East.

The tool steels produced by the crucible route in Europe in the 19th century were different from the Damascus steels of the Near East or the *Wootz* prepared in India. However, it is precisely from the studies performed on the *Wootz* during the 19th century by European metallurgists, that a general scientific knowledge of steel microstructures was developed, and one of the main results was the definition of new high quality tool steels.

Many aspects of the history of crucible steel have already been described in thousands of papers and books. However, the subject of a possible transfer of knowledge or know-how from India to Europe has not been sufficiently analysed.

Before the first circumnavigation around Africa by Vasco de Gama in 1497, the Muslim countries of the Near and Middle East were natural intermediates between India and Europe. As a consequence, it can be imagined that knowledge, or at least current words, concerning oriental steel either of Islamic origin or transmitted by the Arabs from more Eastern countries, might have been transported into the western part of the Mediterranean Sea. This point will be discussed in details.

Concerning the lack of knowledge in Europe on *Wootz* and *Damascus steel*, questions must also be asked on the properties of Damascus swords as compared with Frankish ones, in order to clarify old legends, which are always active.

In the present paper, the interest focus on European sources, not on Arab ones which have been very rich since the 9th century, but unknown in Europe until the 19th century. The discussion will be limited to the period before the end of the 18th century, that is before the first laboratory studies

of Pearson [9], and the important report by Buchanan [10] who furnished to European readers a first description of Wootz production in India. The reason of this choice is that a lot of papers have been published after Pearson and are well known today.

Further, the most famous French medieval epic literature is visited to find indications on knowledge or at least interest, in Muslim and perhaps Indian metallurgical know-how. The Ukrainian-Russian poem "Prince Igor" is also analysed thanks to a new critical publication in French. Other historical sources have been questioned, essentially those from France, Italy and Spain. Finally, a discussion is proposed to clarify the existence of a general "impenetrable barrier" against scientific or technical knowledge such as Wootz, until the 18th century.

For technical sources, the original texts quoted here are given with English translation and critical remarks.

Definitions used here:

Damascus-steel, -blades, and -damasked, when speaking of a forged crucible steel.

Pattern-welded for composite blades, forged from two or more iron or steel parts.

Decorative-damascening for acid attack on ordinary steel and for inlaid of gold or silver wires, on steel or other metals.

Damascening will appear in ancient translations or references. In each case the signification will be precised, when it is possible.

1. THE FIRST METALLURGICAL DESCRIPTIONS OF CRUCIBLE STEEL IN EUROPE (16TH TO 18TH CENTURIES)

1.1 - Tavernier and Chardin

The well-known descriptions of Tavernier in 1679 [11] and Chardin in 1711 [12] are the first in European literature to give useful details on crucible / Damascus steels, their origin, properties and aspect. Complete versions of the texts are given below in translations reviewed by the author of the present paper, and based on those published by Bronson [13]. They

are followed by comments that are proposed to clarify some phrases. The relation between the comments and the text are made by a small exponent like[a]. The original French versions are given in **Appendices 1 and 2**.

1.1.1 - Translation of Tavernier [11]

> "The Persians know perfectly well the damascening[a] with vitriol for instance of swords, knives and the like, but the nature of the steel which they use has a great importance because they could not obtain the same result with their own nor with ours. This steel is brought from Golconda, and is the only sort which can be well damasked. It is different from ours, for when it is put in the fire for quenching it needs no more than a small red like the colour of a cherry, and instead of quenching it in the water as we do, it must only be wrapped in a moist linen cloth, because if it was given the same heat as ours, it would become so hard that when you would like to handle it, it would break like glass.
>
> This steel is sold in pieces as large as our one-sou loaves[b] and in order to know if it is good and if there is no fraud, they cut it in two parts, each fragment being enough to make a sabre[c]; because it happens that some [pieces] have not been well prepared, and which could not be damasked.
>
> One of these loaves of steel, which will have cost no more than the value of nine or ten sols[b] in Golconda, is worth four or five abassis in Persia, and the further away it goes the more expensive it becomes. Because in Turkey they sell a loaf for up to three piastres, and it also comes to Constantinople, to Smyrna, to Aleppo, and to Damascus where anciently it was mostly transported, when the commerce of the Indies used to arrive to Cairo via the Red Sea. But today as much as the king of Golconda makes difficulties about letting steel leave his country as much the king of Persia tries to prevent anyone from re-exporting that which had entered his kingdom.
>
> I make all these remarks to undeceive all those people who think our sabres and knives that come from Turkey are made of steel from Damascus; which is an error, because as I have said there is no steel in the world but that of Golconda which can be damasked without the steel being eaten [by the acid] as does ours".

Comments

a. *Damascening*: there is no ambiguity here, it means acid pickling on crucible / Damascus-steel. In the last sentence of the paragraph, the fact that the steel from Golconda can be damasked without being eaten — I suppose

it is by acid — shows that only a light attack was needed to reveal the Damascus microstructure of the blades, whereas a strong attack was needed to make relief drawings on the surface of ordinary steels. The image from Al-Kindi quoted by Hammer-Purgstal : "*when you look to a sword, you look inside and outside, what is called guher in Persian*", describes what we use to call the microstructure of the metal that you can observe under the microscope on a polished surface after metallographic preparation and you consider as the image of the inside microstructure. The end of the sentence of Al-Kindi says : " ...the same thing that is said in Arab by *djewher*, which is the *substance*". *Substance* is the equivalent of our notion of "microstructure". The French version of Hammer-Purgstall [7:79] gives : "Lorsque tu regardes une épée, tu regardes au-dedans et au-dehors, ce qui s'appelle en persan le *guher* (la même chose que l'arabe *djewher*, c'est à dire la substance)".

b. *One-sou loaf*: this is an interesting image because in old times in France, it was currently representing a round piece of bread of the shape of your hand. It represents a low price, something like a few pennies. This means also, that a ten sols loaf of steel in Golconda is a low price for a French traveller. The word *sol* is the ancient form of *sou*.

c. Such a loaf for making two blades might have had a weight of about 2 to 3 kg. In this case, you need two hands to handle the "one-sou loaf" of bread!

1.1.2 - Translation of Chardin [12]

> "The iron mines are in Hyrcania, in northern Media, in Parthian country and in Bactria. There is plenty of iron, but it is not so mild as that from England. The steel mines are in the same countries, and they produce a great deal, for [but] the steel is there not worth above seven sous[a] a pound. This steel is so full of sulphur[b], that if you throw the fillings on the fire, they will crackle like gun- powder. It is fine, having a very small and delicate grain[c], a quality which naturally, and without the help of art, renders it as hard as diamond; but on the other hand, it is as brittle as glass; and as the Persian craftsmen don't know very well how to temper[d] [quench] it, it is impossible to make springs, and other minute and delicate[e] products. However, it takes a very good temper [quench] in cold water, which is accomplished by wrapping it in a wet cloth, instead of throwing it into a trough of water, after it has been heated without allowing it to get completely red.

> This steel cannot be joined[f] with iron, and if it is put into too hot a fire, it burns, and becomes like the dross of a coal. They mix[g] [combine] it with steel of the Indies, which is softer, though it be also full of sulphur[b], and hold in much more esteem. The Persians call both sorts of steel poulad jauherder, wavy steel (*) which is that we call Damasked steel, to distinguish it from the steel of Europe.
>
> It is from this steel that they make their beautiful damascened blades. They melt[h] it down in a round loaf[h], like the hollow of one's hand, and in small square bars[h]".

*(The following note from the 1811 edition has not been published in English). *Poulad jauherder or djauherdâr,* signifies literally steel which has waves. It is not useful, I think, to remark that steel is not found in the mines, but that it is prepared by treating mild iron in certain processes described in the Metallurgical Books. This observation did not escape to the author of the *Nozahat-al-qeloûb*, from where I will extract the paragraph on the iron mines:

> "*There is plenty of it, does he say, in the kingdom of Qaban which makes it receive the name of forge. The mountain of Féçâs (or Qaçâs) in Arabia, contains an iron mine so good that they can make steel from it; the sabers named feçâcy (or qaçâcy) are famous for their good quench. Qathrah, in the province of Thârmyn and Quazwyn contain iron mines that give an excellent steel. The mines from the region of Khoùâf, from the Qoubestan, from Faran and from the province of Fars are also very famous for their good steel. We can also quote those of Kundjaqh, from Gulnyz, from Azerbâïdjân and from the mountain of Beler Koudjek or Little-Beler*". [Persan Manuscript, n°127, page 269. (L-s)[2]].

Comments

a. *Seven sous*: compare with Tavernier just above. The prices are of the same order of magnitude.

b. *Sulphur*: generally written "*sulphurs*" with a plural, representing all materials able to burn, such as common sulphur or what we call carbon, contained in charcoal, grease, etc. Here it is question of the high carbon content in filings from the steel.

c. *Delicate / grain*: the French word is "*délié*", which can be translated by *fine* or *minute*. Here, concerning the "*grain*", it is a quasi-repetition of *fine* attributed to steel. The grain was defined by the aspect of the fracture

surface (see Réaumur), and has nothing to do with our actual notion of grain size.

d. *Temper / quench*: in the text of Chardin, it is clear that "temper" can be translated by quenching. However this term of *temper* had no general clear signification at these times and covered different heat-treatment of metals.

e. *Minute / delicate products*: *minute* is proposed for "*délié*" that is very fine or small; and *delicate* would mean here: difficult to prepare or to handle because it could be brittle. This cannot be considered as a precise description.

f. *Joined*: the French word is the verb "*allier*", which means *to alloy*, but here the signification is certainly *welded by forging.*

g. *Mix / combine*: the French verb "*mêler*" can be translated into *to mix*, which gives the idea of melting together, or by *to combine* that is forging together two pieces of metal in order to make a composite blade between a brittle Persian steel and a milder Indian one. Chardin says also that the Persian and the Indian steels are of the same nature called "Poulad Jauherder", but it is not evident to conclude between the two possibilities, *remelting* or *combining by forging.*

h. *Melt / loaf / square bar*: It is not evident that Chardin had access to the preparation by melting and solidification of what he called "loafs or square bars". His description could concern a loaf in the as-solidified state or a semi-forged product having the shape of a square bar. This remark would be consistent with the observation of Moxon (see below) that this steel came rarely unwrought in Europe. However, Al-Jildaki in the 14th century [4], translated by Al-Hassan [5:38], explained that the solidification of steel was performed into bars or egg-shaped ingots:

> "Thereupon, they pour it out through channels so that it comes out like running water. Then, they allow it to solidify in the shape of bars or in holes made of clay fashioned like large crucibles. They take out of them refined steel in the shape of ostrich eggs, and they make swords from it and helmets, lanceheads, and tools".

Such a description of cast steelbars is surprising because a steel bar in the as-solidified state would contain solidification pipes, which should make it unusable. Probably these bars would have been cast iron.

1.2 - G.B. della Porta (1558) and J. Moxon (1677)

Smith [16:24] quoted these two authors on the difficulty of working oriental steels. However, it seems that the publication of della Porta has not been completely analysed.

1.2.1 - About della Porta, [14] Smith wrote: "Porta says that it [the steel] can be worked after it has been annealed in calcined gypsum [i.e., lime] and slowly cooled". The bibliographic reference given by Smith is not enough precise because there have been several editions and versions of Porta's book. The first in 1558 contained only 4 Books in Latin and many additions were made later. In the English translation of 1658, the chapter N° 13th "*Of tempering steel*" is particularly interesting because it explains how to *temper* [quench] steel in different media for different employments: for instance ordinary knifes to cut bread or extra-hard files. He also explains how to stop cooling at a define colour (temperature) and continue cooling in another medium and finely, how to anneal the metal after quenching. This clearly means that he had a quite precise knowledge of heat treatments of steel. In the part "*how damask knives may be made*", clearly della Porta is not speaking of Damascus steel but of "damascening" and especially decorative-damascening with inlaid of silver and gold. This text is given in Appendix 3, in which the use of gypsum is cited, as reported by Smith, but not the term "slow cooling". Without doubt, there have been modifications in the numerous editions of della Porta, but finally, it seems that della Porta had no knowledge of crucible steel.

1.2.2 - Moxon [15]. One century later, Moxon referred to the fact that this steel "very rarely came unwrought into England", as explained by Smith and that: "It is the most difficult of any steel to work at the forge, for you shall scarce be able to strike upon a blood heat but it will Redsear[3]; in so much that these Symeters are by many workmen thought to be *cast steel* [4]; but when it is wrought it takes the finest and keep the strongest edge of any other *steel*" [5]. Moxon had several talents including that of engraver, which made him appreciate the high cutting properties of Oriental steel.

1.3 - Remark on Marco Polo [17]

A special remark must be done on words used by the Venetian traveller Marco Polo writing at the end of the 13th century, when (using our today

language) he spoke of an iron base alloy that he considered as different from ordinary steel. In the chapter: "Concerning the Kingdom of Kerman", he said: "There are also plenty of veins of steel and ondanique ...". The first observation is that "steel" and "ondanique" are not the same metal. In different reports and translations of Marco Polo's book, we can find: *andanicum, andanique, ondanique*, etc. This word is generally considered as a modification of *hundwani*, signifying: "from India" [18]. Without doubt, this interpretation is right, but it could also have happened that Marco Polo made a play on words, because *ondanique* sounds like "*ayant des ondes*" as said by Chardin for *Jauherder*, or *showing waves* or *watering*, because "*onde* or *onda*" coming from "***unda***" in Latin means: ***wave***, related to *watering* or *watered.*

1.4 - Réaumur (1722)

In his famous report from 1722 [19:259], Réaumur relates how he received from Cairo [6]: "... steels of which the famous Damascus swords are made... Among the steels ... there is a loaf [pain], which is called steel from India and the most esteemed in Egypt; there is no artisan in Paris who succeeded in forging a tool from it. It withstood fire hardly better than cast iron. Other steels from the Levant [Near East] are ordinarily difficult to forge but less than this one" [13]. It can be noticed that in the 570 pages of the Réaumur's book, there is no other mention of Damascus steel.

This means that steels from Near and Middle East were occasionally forged in Europe and that their particular behaviour during hot working was known. Réaumur makes a difference between the Near East steels and the loaf coming from India, which he compares with cast-iron. The shape of the ingot shows that it is in the as-solidified state, that is: not previously wrought. Unfortunately Réaumur does not describe the shape of the other pieces of steel coming from Cairo. Maybe, they were already wrought as noticed by Moxon (see above), and this would be an essential difference.

1.5 – Diderot (1751)

In the *Encyclopaedia* of Diderot and d'Alembert [21], there is only a short mention (article: *Acier*) of the fact that Damascus steel was well known but not commonly used in Europe [7]

1.6 - Biringuccio (1556)

Biringuccio gave a list of the best known steels [22a]. In the French translation of his book (1572) we can find (English words by myself): "... that of Flanders and in Italy, that of Valcamonica in the Brescian country, & outside the Christendom, that of Damascus, of Cecilia, or Caraman and the gemmino or porfien called Agiani ..." [8]. In a new English edition of 1942 [22b], based on a critical linguistic work, a few interesting differences appear: "...outside the Christendom the Damascan is praised and the Chormanian, the Azziminians and that of Agambians".

It is not essential, for our present discussion, to decide which of the 16th century French or the recent English edition is the closest to the original because the important point for us is that all the words used in both versions are from the 16th century. However, it is not easy to localize the cited places.

**Cecilia*: Sicilia is improbable because it was a Christian country in the 16th century under the authority of the King of Spain. Maybe Cilicia in Asia Minor? Other possibility: steel imported via Sicilia?

**Agambian*: I have no proposal.

**Agiani and Azzimian*: a relation can be proposed in the following way. *Azzimina* was the Italian name of a process, called "*lavora all'azzimina*", a decorative-damascening by inlaid of gold wires into steel or other metals. At the Renaissance (16th century), the best known Azzimians of Europe were in Italy. This knowledge had been imported from Syria to Venice. The relation with "gemmino or porfien" is clear: gemmino is very close to gemmo in Latin, which signifies "covered with gemma" (precious stones) [23] and porfien looks like porphyry of Greek origin, the name of a dark-red colour, and a kind of stone. In French, porphyre was written: "*porfire*" in the 12th century [24] and "*porfie*" in the 13th century [25]. It seems likely that "gemmino and porfien" describe the decorative-damascening work of Azzimians. Furthermore, the word "Azzimina" is related to the Venetian *agemina* coming from the Arab *al-'ajem* [26], which signifies "foreigner", that is: *non-Arab*, in the present context. In the French translation of Biringuccio, *agiani* is clearly a transcription of *al-'ajem*. Consequently, this discussion shows a technical knowledge of decorative-damascening coming from Arab countries, but nothing related to crucible steel.

**Chormanian* can be understood as a place in India or Persia. In Latin [23], Choromandae is the name of a people of India (Pliny). In old and modern Greek "khôra" (cwra) signifies "region" [27], and Pliny says that Mandaei or Mandi is the name of a people in India. These considerations would explain "khôra-mandae". Furthermore, Mania is also used by Pliny for a town in Parthia, the old name of Khorassan at the East of Iran.

**Caraman* seems different from Chormanian. It could correspond to the "Kingdom of Kerman", quoted by Marco Polo (see above, §1.3). An other name of Kerman was "Carmania". In 1816, Baker the British Consul of Aleppo bought two *swords from Caramania*[9]. His description of the rehabilitation of the blades, which were in a poor state of conservation, is particularly interesting [8:58].

1.7 – Partial conclusions

From this meagre list of western technical sources, it can be concluded that a knowledge of the existence of steels from Near or Middle East and from India was effective in Western Europe, but at a very poor level as compared with the rich Arab bibliography on the subject of crucible steel since the 9th century. It is clear that no practical knowledge was transferred during centuries from the Eastern to the Western smiths. The first understanding in Europe of the nature and properties of the Indian Wootz or Middle East crucible steel was only obtained by experiments by Pearson in 1795 [9] and several researchers in the 19th century [13, 16]. On the method of crucible steel preparation, the report by Buchanan in 1808 [10] was the first to give a precise description of the furnaces and metallurgical conditions. A transfer from Eastern to Western technology happened only when some Europeans became able to open their eyes on those goods that were not the most precious such as silk, jewels, spices, etc.

This first conclusion is surprising because Christians and Muslims have been in contact sometimes fighting but sometimes not, during the two centuries of the Crusades (11th to 13th) and the eight centuries (8th to 15th) of existence of Al-Andalus that was the name of the southern part of Spain (see below). However, our sources are certainly not complete. New researches are desirable and the question must be asked if useful testimonies might be found in the Middle Age literature.

2. EPIC LITERATURE OF THE MIDDLE AGE AND CHRONICLES OF THE CRUSADES

2.1. Western origin

From Charlemagne (8th century) to the end of the Crusades (14th century).

2.1.1 Epic literature

The Song of Roland [28], an epic poem written in the 11th-12th century describes a battle between Charlemagne's army and Saracens, which happened in 778. The date of the battle is right but, in reality, the Saracens were not present. Charlemagne was returning to France, after a campaign in Spain against the Saracens. In Roncevaux, a pass in the mountains, the rearguard of the army, which was under Roland's command was defeated and plundered. The enemies of Roland were not Saracens but inhabitants of the mountain. However, this detail is not essential because the poem was written at the time of the first Crusades, after a long contact between Christians and Saracens since the 8th century in Spain and France, which might signify certain knowledge of the arms of each other.

It has been proposed sometimes that the marvellous sword of Roland that could not be broken by a blow on a stone was from Damascus steel, but no direct information can be found in the poem. Only indication is available on the colour of the blade: brown or burnished[10], which might be related to Damascus blades. It is well known that the colours of the blades are different as a function of the nature of the Damascus steel and the last step of pickling [7:72-75, 8:54-62, 30:629]. However, brown is quite frequently cited.

In the Song of Roland, these terms related to colours do not seem to represent a real quality of the metal. They are always *used at the end of the verses to produce assonance* as can be seen from the examples shown below, from the Old French text. It must be noticed that this remark is impossible in a translation either in English or in modern French!

For instance in the part number CXXVI, the assonance is "*an/en* = ã" for the eight verses of the "*laisse*" (a paragraph):

La bataille est e merveillose e grant.

Franceis i fierent des espiez ***brunisant.***
La veïssez si grant dulor de gent
Tant hume mort e nasfret e sanglent![11]
...

Other examples, CXLVI: " ... *Haltecler dunt li acer fut bruns"*, (Hauteclere the steel of which was burnished), and CLV: " *Il trait Almace s'espee d'acer brun*, (He draws Almace his sword of brown steel), in which the assonance is on the vowel "*u*" with the phonetically pronunciation "bryn".

Hauteclere is the sword of Olivier a Christian knight and *Almace* that of Turpin, a fighting Archbishop. *Durendal* belonging to Roland is *blanche* (white), once more a last word of a verse used only for assonance in "an/am = ã":

CLXXII : *E ! Durendal, cum es bele e clere e blanche !*
Cuntre soleill si luises e reflambes![12]

More interesting: about *Precieuse*, the sword of the Saracen Emir named Baligant, there is no description at all, which suggests that the swords of the Saracens were not considered as different from those of the Christians. More generally, the images used to describe both armies and the ways of fighting are always the same.

Generally, the blades are *shining*, *glittering*, etc. and *cutting*, but these images had been common for many centuries, as can be seen in a letter from Theodoric (6th century) quoted by Smith [16] on Merovingian/Frankish swords[13] and also in poems such as *Beowulf* [31a] written about the 10th century. Beowulf has nothing to do with the wars against Saracens. The poem tells the story of a Swedish Prince of the 6th century going to Denmark to kill a monster. In the 10th century poem of *Judith* (same manuscript as Beowulf...), a famous Virgin of the Hebraic Bible, the French translator used: "...lames au *damas* étincelant, aux tranchants éprouvés..." [14]. It is given in a modern English edition by "finely-decked swords" [31b] from the Old English "scirmaled swyrd" [31c], where *scir* means "clear, shining" and *mael/mal* is something like a mark, applied here to the inlaid [31d]. The use of "damascening", in the French version, to qualify a sword of the 5th century is at least anachronistic!

Another well-known wonderful sword is *Escalibur* the sword of the mythic King Arthur in the Celtic cycle. At the moment of his death Arthur spoke a long time to his sword that he qualified of "good and beautiful" without any other description. The poem was written in the 13th century [32].

For the present work the following books were also analysed:

Le Chevalier à l'Epée from the12-13th century (The knight and the Sword). It is the story of a marvellous sword protecting a nice young lady. Only the rich pommel is described [33].

La Manékine (13th century), the tale of a Princess who was condemned to have her hands cut, etc. Many countries are involved in the narration, France, Italy, Hungary, Scotland and Armenia but they are only virtual places [34].

Mélusine (14th century) tells the history of the Lusignan family that gained the Kingdom of Jerusalem and Cyprus during the Crusades. This fact is historically right, but Mélusine is a Fairy [35].

In the 8185 verses of *Aliscans* written at the end of the 12th century [36], only one word "*outremer*", which means "beyond the sea" is interesting for our present purpose. It appears two times: "*épieu au fer d'outremer*" (spear with iron from beyond the sea) in verse 5860 and, in verse 7890: "*soie d'outremer*" (silk from beyond the sea), without explanation on the localisation of this "*outremer*". However, in Guillaume de Tyr (see below), "outremer" can be clearly identified with the Near East: Syria, Palestine and Asia Minor [37].

In the epic literature, people were more interested by the decoration of the pommel and hilt, than the nature of the metal of the blade. There is no technical description of arms and the fighting sequences are always the same: first on horseback with a spear, then with a sword on horseback and finally on foot after falling from the horse. Whatever the époque, a common strong image of the heroic literature shows the warrior cutting the enemy into two pieces from the head through the whole body and even through the horse, with only one blow of his sword.

2.1.2 Chronicles of the Crusades

The 480 pages of the "Crusade Chronicles" were written by Guillaume de Tyr (about 1250) when he was archbishop of Tyr in Syria. He explains

essentially the factual history without details on armaments. Sometimes a few technico/tactical words are given on battles between Muslims and Christians [37], but without usable substance.

Two other well-known chroniclers have been present as warriors during the Crusades.

Villehardouin [38] during the IVth Crusade (1202-1204) was an actor of the Conquest of Constantinople, a fight between Latin and Byzantine Christians. The main part is the terrific description of destruction, plundering, violence and murders in Constantinople by the Latin Crusaders on the Byzantine Christians.

Joinville [39] was part of the VIIth Crusade (1248-1254) with the French King Louis IX, also called St Louis. He wrote a chronicle on the campaigns but no description of swords is given. Sometimes he says that the Saracens had "glaives" (gladius) when Christians used "épées" (swords); one time a beautiful sword was described as an "épée d'Allemagne" (a sword from Germany).

La prise d'Alexandrie (The Capture of Alexandria) by G. De Machaud (14th century): A description of the last Crusade. The author had never been in the Levant [40].

2.1.3 Partial conclusion

No technical knowledge and only scarce lexical indications have been found in Western epic literature and in Chronicles of the Crusades. The poets and chroniclers were not interested by iron and steel metallurgy and the descriptions of arms are not enough precise to be usable for our purpose.

2.2. Russian-Ukrainian domain

A description of the transfer of populations through the Steppe is not proposed here. The only aim is to comment the famous *Prince Igor* poem, which has sometimes been compared with the Song of Roland [29b].

Large parts of the Russian-Ukrainian domain have been under Mongol influence from the 13th to the 15th century, with many relations with Persia and India. The *Slovo*[15] [Song] of Igor describes the fight in 1185, between

a Ruthen[16] prince and the Polovtse nomadic population from Turco-Mongol origin. In the poem the word *Kharalough* appears four times as an adjective.

Lebedynsky, in a new edition of the poem, containing the original in Ukrainian, a French translation and detailed comments, proposes the addition of the word *steel* to Kharalough [41]: "acier de Kharaloug", which we can understand either as "steel from Kharaloug" (a region) or "steel made of Kharalough" (a material). The association between Kharalough and steel is probably right because the adjective is attributed to swords or spears but also to the heart of princes!

Kaharaloug has a Turkish consonance [41:n.16] and two different significations are possible: either *Karlouks* (Qarluq), a Turkish population of Central Asia, or an indication of the colour of the steel because *qara* means *black* in Turkish. This adjective was currently attributed to two types of Damascus swords: Kara-Khorassan and Kara-Taban [42, 43, 44:197].

The problem can be complicated by a nationalist point of view. In his Russian publication, Anossov [44a] wrote that Igor's army was fighting with "Bulat" swords, which was translated into "sabres de Damas" (Damascus sabers) in the French version of the same paper [44b]. Belaiew [29b] explained that the name "Kara-lugh", which he calls *the Asian steel of people of Turkish origin,* was replaced in the Russian documents of the 15th-17th centuries by "Bulat". Unfortunately, no reference is given to support such an assertion and, in the above quoted original poem, the only word used is Kharalough. The question of the origin of Bulat derived from Poulad / Fulahd, and its transfer to Russia from Eastern countries is not discussed here. However, it is important to remark that the transfer of Bulat from Russia to Western Europe did not happened.

A fundamental question about the Igor poem is the date of its creation. As a function of your patriotic conviction and your linguistic culture, you can chose between the 12th century, when the real battle took place and the 18th century when the manuscript was discovered (1792). It was published in 1800 and disappeared in 1812, when Moscow was destroyed by fire during the Napoleon's invasion of Russia.

Once again, this epic poem presents no technical description. Its role is to worship the heroes and the poets were rarely present on the battle stage.

Consequently, it is necessary to find other sources by the study of archives and archaeological researches.

3. OTHER HISTORICAL DOCUMENTS

Two recent documents treating of archives and historical questions are analysed here. The first concerns the Carolingian period in France and the second gives information on the period of domination on Spain by Muslim Emirs. Interesting information is found in these two papers and, for future research, maybe other specialised publications, for instance on arms, would give new indications, but research in this domain can be developed only by specialists.

3.1 A STUDY OF CAROLINGIAN ARMS

Coupland (1990) [45] published a precise and very well documented paper on Carolingians arms of the 9th century, in which new information is given from archives in Latin in which appears a quotation of *spata India / indica:* "The Saracens ... recognized the quality of Carolingian swords, as is indicated by their demand for one hundred fifty such weapons as a part of the ransom for Archbishop Rotland of Arles in 869". On the other hand, the Franks seem to have prized Saracen swords equally highly, and one of Charlemagne's vassals is said to have captured from the Moors "***spata india*** cum techa de argento parata" [17]. Further: "*Count Eccard of Macon* [a city in Burgondy-France] *left a* ***spata indica*** *in his will*[18] ...". Coupland explains that *spata india* was a *Saracen sword,* which shows that it was a name given by Saracens to a particular type of blades or steel.

A second important point concerns the disappearing of pattern-welded blades of the Merovingian type [16:4] at the end of 9th century, first affirmed by France-Lanord [46:418] [19]: " At the end of the 9th century, the fabrication of damask swords [pattern-welded] stops abruptly; they are replaced by a completely different fabrication. That of swords whole out of steel, with a quite homogeneous metal, on which one of the first manufacturers wrote his mark : Ulfbert", (trans. by myself). Smith [16:4] quoting France-Lanord says: "... the sudden disappearance of the pattern-welded blades in the tenth century suggests localized manufacture [France-Lanord proposed the Noricum province of the Roman Empire, situated in Austria between the Danube and

the Alps], for the blades were highly valued and it is unlikely that catastrophe would have suppressed a widely scattered skill. It is possible, of course, that they were displaced simply by the development of cheaper and equally efficient methods of making and heat treating uniform blades, or blades with welded-on edges of steel". Smith uses "pattern-welded", when France-Lanord speaks of "damassé".

Coupland writes also: "During the reign of Charlemagne, Frankish smiths discovered how to improve not only the strength of the blade but also its manoeuvrability... the Carolingian spata (long sword) also became highly prized by hostile neighbours such as Saracens and Danes". Unfortunately there is no precise information on the kind of technical improvement.

However, pattern-welded blades, or "blades with welded-on edges of steel", a phrase used by Smith [16:4], were still in use centuries later. In the 14th century, Ibn Hudhayl [Hodeil], writing in Granada (Spain) described the differences between Frankish blades and those made of Indian steel [47]: "If the two edges of the saber are of steel while the blade itself is of iron, the saber is called mudakkar (steeled), which is typical of Frankish swords. 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 hindy saber often breaks when the weather is cold and shows itself better when the weather is warm"[13:20, 47] [20].

Zaky [48] explains that the Andalus smiths emigrated to France under the pressure of the Saracen invasion into Spain, without giving any reference in his paper.

Summary. Two important points have been found here:

* The phrase *Spata India* was known by Carolingians as a name given by Saracens to a special quality of sword.
* The new Frankish swords had been prized by Saracens since the 10th century and until at least the 14th century.

3.2 Al-Andalus

The history of Medieval Spain is particularly interesting because during eight centuries, from the beginning of the 8th century to the end of the 15th

century, the Saracens dominated a large part of the territories of Spain and Portugal.

The question of transfer of knowledge from East to West is well documented in mathematics, science, medicine, etc. In the Emirate of Cordoba, a lot of translations were performed, first from Greek to Arab by Muslim scientists and later to western European languages. This period is very often described as harmonious between Muslim, Christian and Jewish people in Spain. However, the real situation was certainly not so ideal and the Muslim religion (as the Christian) not so liberal to science as it has been commonly related. The intellectual positions of Avicenne (11th century in Iran) and Averroes (12th century in Cordoba) were not always well received by the religious authorities, and the conservative forces were active to defend the Muslim Revelation, as was also the case for the Christian Revelation, against those who developed ideas of Aristotle and others Greek philosophers. However, it seems that the fight of the religious power against scientists and philosophers was not so brutal, at these times, under the Muslim rule as it was under the Christian one (see below).

The recent paper by Dinnetz (2001) [49] evaluates the literary sources from Hispano-Arabic and early Castilian languages (Spanish) on the production and working of crucible steel in medieval Spain between the 10th and 13th centuries. Dinnetz first observes that: "A number of authors (Forbes 1957; Calvo 1964; Lombard 1971; Glick 1979) have claimed that crucible steel was imported to, and used, worked and produced in Islamic Spain, without presenting any literary or physical evidence in support" and then he concentrates his work on primary sources.

Dinnetz shows that a special name was given to a steel that is likely to be a crucible steel: *alfinde, alhinde* (p.75) in Castilian language, coming from the Arab word *al-hind* and its variations: *hindiyya, hinduwani* (p.74). The reference to India does not mean that the steel was coming from India but that it corresponded to a certain quality of metal. In the paper by Coupland [39] (see above) the reference to "spata indica" had the same signification when he said that this term was part of the Saracen vocabulary. In Castilian, a clear difference was made between *al-hind* and ordinary steel that was called *açero*.

Unfortunately for our discussion, the references to *al-hind* were not in Castilian writings. They were essentially found in Arab literature. However, a few Castilian texts show the difference of nature between *açero* and *alfinde*: for instance [49:76] about the legs of a compass: "... this movable shank should be of steel (açero) or of Indian steel (alfinde) ...", found in a book written for Alfonso X in 1277. An identification between alhinde and andanico is also affirmed: "... there is iron to which, upon melting, medicaments[21] are added by which it makes itself so strong [hard] that it cuts the other kinds of iron, and this the Moors call alhinde, and in some lands it is named andanico ...", found in another book for Alfonso X, in 1278. The strong cutting ability of this steel is applied here for engraving on metal. Like many authors, Dinnetz (p.77) says that *andanicum* used by Marco Polo (13th century) is coming from *hundwani* (see above, §1.3).

The existence of a local production of crucible steel in al-Andalus by Arab smiths is supported by a quotation in Castilian, from 1293 [49], but the subject has to be studied more precisely [51:23]. Arab writers [1, 2, 3:127] considered, however, that the quality of the iron mines and steels produced in Spain were not the best for making swords[22]. It would be necessary to re-examine this subject.

The conclusions of Dinnetz are: (i) that Christians were aware of the quality of crucible steel but they did not to know how it was prepared, and (ii) that they did not prepare this steel, and he adds "at least until the 13th century", because there is no projection after the 13th century, in his paper.

4 . DISCUSSION

Two complementary aspects are exposed below to clarify the situation that can be summarized as follows: the existence of oriental hard and cutting steel was known but no transfer of technical know-how was done in the preparation of crucible steel and forging of high carbon steel during one thousand years. A first aspect is related to the history of Europe, and the importance of the religious power, which imposed an impenetrable barrier against evolution. The second aspect is technical and concerns the following question: why Europeans seemed to have had no need of the special properties of Oriental steel for sword making or civil applications?

4.1 The impenetrable barrier

Question: Were civilisation differences important enough to reject a knowledge transfer? An historical description is proposed here, of the political and social predominance of the religious power of the Roman Church in Europe and its consequences on the absence of transfer of knowledge from East to West until at least the Renaissance (16th century).

4.1.1 Short historical description of the period[23]

The Roman Empire created a large domain in Europe and around the Mediterranean Sea facilitating commercial circulation. From the end of the 4th century, a step by step separation between a Western and an Eastern Empire took place, each of them following different evolutions until the Great Schism, in 1054, that separated the two Christian Churches: the Catholic under the authority of Roma and the Orthodox under the rule of Constantinople (Byzantium).

In the Western Empire, the invasions of Eastern and North European people followed by those coming from the Oriental Steppe, from the end of the 4th century to the mid 7th century, had for consequences the parcelling of the territories and the interruption of commercial routes. The different tribes that took a military power over the local populations wanted only to assure their local domination and increase their territory by war. The last residual power of the destroyed Roman Empire was the Christian Church, a situation that was rapidly understood by the new chiefs of war who decided to build their military strength on the religion as a strong tool for the domination of the local populations. At the end of the 8th century, Charlemagne succeeded with the support of the Roman Church to build a new Western Empire covering approximately France, Germany, the north of Italy and a part of the north of Spain. Charlemagne was sacred Emperor (the same title as Caesar) in 800 by the Roman Catholic Pope.

At the same time, in the Eastern part of the Mediterranean Sea, the Byzantine Empire resisted to Northern people invasions and to the beginning of the Muslim expansion.

Since 711, Muslims had invaded Spain and built very well structured kingdoms that integrated the former Visigoth culture, and developed a refined oriental civilisation unusual to the Western warriors. The Muslim expansion

towards Europe was limited to Spain after the battle of Poitiers in France (in 732). However, the Saracens continued their occupation of the south of France (see *Aliscans*, § 2.1).

During the 9th century, three empires were face to face around the Mediterranean Sea: a first Christian one in Europe under the Carolingian power, a second one at the South East of Europe under Byzantine control and, East and South of the Mediterranean Sea, a large Muslim congregation of countries following common rules but not always dependant of a unique central power. The main contacts between Christians and Muslims were in Al-Andalus (Spain) and at the Byzantine borders.

After Charlemagne, the Western Empire broke up, first into small kingdoms and rapidly into feudal domains in which each local chief of war imposed a despotic rule on the farmers, while spending his life in wars against his neighbours. The Crusades were a nice opportunity for the Roman Pope, to send the warriors eager for conquests and oriental pleasures, to the Near East with an imperious and noble motive: the liberation of the Christ's Tomb, which was under the rule of Muslims. This Holly mission lasted two centuries from 1095 to 1270.

At the end of this period, the Christian Kingdoms of Palestine disappeared and, at the opposite side of the Mediterranean Sea, in Al-Andalus " La Reconquista" from 1031 to 1236 let only a small Muslim kingdom around Granada, which fell in the hands of the Christian Spanish King, much later in 1492. However, a positive consequence was the opening of the commercial routes from and to the Near East, to the great benefit of the Italian traders: Venice, Pisa, and Genoa. The Byzantine Empire was still alive but declining after the Crusaders sacked Constantinople (1204) and imposed a Latin (Western Europe) power. The Turks were advancing in Asia Minor and around the Black Sea, especially in the Balkans. However, Constantinople resisted until 1453. After the end of the Byzantine Empire, the Turkish Empire accelerated its expansion around the Mediterranean Sea.

In Europe, after the Crusades, wars between European countries were continuous, for instance in France the 100 Years War (14-15th centuries).

Contacts with Middle East and India were not direct because the terrestrial route (the Silk Road) crossed Muslim countries and the sea route

from India stopped in the Persian Gulf [24]. It means that the Arabs traders were necessary intermediates between Europe and India, until Vasco de Gama opened the direct maritime route by the South of Africa at the end of the 15th century. At the same time Christopher Columbus sailed to America and in both cases the main interest was for precious goods such as gold, silk, spices, jewels, and for the expansion of the Christian religion, establishment of new empires and commerce of slaves, etc.

4.1.2 The social predominance of the Christian Church from the end of the Roman Empire to the French Revolution (1789)

A fundamental difference is generally noted between the Muslim and Christian worlds in scientific and technical approaches during the Middle Age and until the Renaissance.

Muslim philosophers studied the Greek culture and it is well recognised that they saved the knowledge of the Greek world (Aristotle, etc.) and developed mathematics, astronomy, medicine, etc. They also introduced knowledge from India; the best evidence being the Indian numeral and position calculation methods using the zero number. At this time the experimental science was developed and enriched by Arab scientists.

In the Western Christian world such possibilities not only were quite impossible but much more, they were strongly forbidden by the catholic religion. The Church had a political function by crowning the Kings and the Emperors and a dogmatic one, which imposed that all knowledge, religious or scientific, had been revealed and no modification could be accepted. Out of this tight frame, everything was considered as *heretic*. The complementary function of the Church was then repressive. At the end of the 12th century, the religious Inquisition tribunal, independent of civil courts was funded to condemn heretic people and schismatic movements. For instance, among the best-known people burnt as heretics were Joan of Arc in 1461 (France), a famous female soldier who saved the King of France (!) and Giordano Bruno, a scientist in 1600 (Italy). Galileo was obliged to retract his affirmations on the rotation of our planet (1633) and even at the "*Siècle des Lumières*" (Age of Enlightenment), the great Diderot was thrown into jail in France (1746) for his "Letter on blind people", and the Encyclopaedia was forbidden after the publication of the first volumes. The Inquisition was very active until the

16th century but it was only in the 18th century that it was officially dissolved. France, Italy and still more Spain have been mostly concerned in this dark period.

After this general description, the obvious conclusion is: *In the catholic Europe, transfer of knowledge from elsewhere was forbidden and every tentative was punished, often to death.*

Here is a typical example: the Arabs had been using the Indian numeral system including zero and the position calculation rules, since the 8th century [53:283]. It was only in the 13th century, that this knowledge was collected in Bougie (Bejaia in Algeria) by the Pisan Leonardo Fibonacci. He was a great mathematician and wrote his first book, *Liber abaci*, in 1202. The Church imposed its veto on this *diabolic* method, which remained forbidden until the 15th century, to protect the clerks that had the monopoly of calculations [53:301]. The funny consequence is that in the 14th-15th centuries, it was possible to learn addition and subtraction in the French and German universities, but it was only in Italy that multiplication and division were taught, because of a better culture by contacts with Arabs and Byzantines [53:290].

Partial conclusion: Scientific and technical transfer had to be carefully hidden and it was particularly the case in Spain where the Inquisition was extremely brutal until the 18th century. As a last remark on metallurgical know-how transmission, it must be added that smiths have never been inclined to give their secrets to anybody and still less to enemies. Only interested observers aware of technical know-how would have been able to catch such new knowledge. It has been rarely the case before Tavernier, Chardin and Buchanan. A discussion of this point has been developed by Bronson [13:27].

4.2 Why Europeans did not understand the interest of Oriental crucible steel?

Question: Was a technical transfer on crucible steel necessary or not to Europe, for special applications, before the 18th century? More precisely, did the non-transfer prevent the development of efficient arms, for instance of sword technology?

4.2.1 What was the importance of swords in the battles?

The *Impenetrable Barrier* was strongly efficient during ten centuries and the situation was unfavourable for open transfer of knowledge from Muslims to Christians. However, another point of view must be discussed concerning the reasons of the apparent low interest of Christians for Muslim swords. This last observation is not enough precise because a reciprocal appreciation of the swords of each other fabrication has been related (see above). This means that the swords of Muslims were not more efficient than the Christian ones, an observation opposite to the opinion commonly exposed by people -who never give a reference- of the fact that during the Crusades, Christians feared strongly the Muslim swords. This simplistic opinion is not expressed in the Chronicles of the time of the Crusades.

Further, the importance of swords during the battles is not universally demonstrated, except in the description of duels between knights in the epic literature. In the Christian writings on wars of the Middle Age, spear, bow and crossbow were more important than the sword that was used for individual fights by horsemen, that means by rich people. In the famous book of Al-Tarsusi dedicated to armament [3], the place given to swords is not so large, as compared with the description of other armaments such as: spears for fighting on horseback, shields, maces, bows, crossbows, war machines, and also naphtha in bottles like Molotov-cocktails.

Moreover, referring to Al-Tarsusi [3:148], in the chapter describing how to organise the battle field, it appears that the quality of arms was understood as only a part of the overall efficiency of the army.

Finally, it is well known that the sword was (is yet) a complex symbol in which the beauty took a large part even if the mechanical properties were not the best .

4.2.2. On the hardness and brittleness of Damascus steels

As explained by Al-Kindi [1] all Damascus blades had not the best mechanical properties. Some of them had high qualities but others were bad, as a function of their geographical origin, and certainly depending of the know-how of the smith.

The high carbon steel used for oriental blades are hard, cutting but also more brittle at low temperature than the Frankish which "... are more resistant to the blows one gives with them during cold weather, while the hindy sabre often breaks when the weather is cold and shows itself better when the weather is warm" [25] [47, 13:20]. It is a common observation for metallurgists that increasing the hardness of steel leads generally to a more brittle product. The brittleness of high carbon steels has also been cited as a problem for Japanese swords[26].

Ragib [8:65] making reference to al-Kindi, in the 1952 edition by Zaky [1], gives a few examples of bad cutting ability or of extreme brittleness. For instance some blades called the "*white from Yemen*" were not recommended by cold weather. Anossof [44:262-3] prepared several Bulat / Damascus blades in the mid 19th century, and as a metallurgist, he was able to make critical distinction between the in-service properties of steels. He explained that a good Damascus blade, quenched in the same manner as steel, could make a notch in this steel without suffering damage. A bad Damascus blade, as some from Khorassan, will make a notch but will be broken. He also recognized a hard Damascus with high cutting property and a tough Damascus with high elasticity. Anossof explained that it was possible to bend a Bulat blade to an angle of ninety degrees without damage and return to the initial shape. The mechanical testing results of Zschokke [30:656-658] on several Damascus blades are not so convincing; the breaking angle is less than 60 degrees [13:25-26].

The hardness of Damascus steel was appreciated for cutting tools such as for engraving (see above Al-Andalus, Moxon who was an engraver and also Chardin speaking of spring making), but such applications are less attractive than sword blades and consequently, testimonies on ordinary tools manufacture are not currently reported.

To summarize, it is not evident that Damascus steel was really interesting for European sword makers, which were able to propose blades with suitable properties, maybe after the improvement of Frankish swords technology that happened at the end of the 9th century [16, 45, 46]. However, for mechanical cutting applications, Damascus steels seems to have been used in Europe for different handicrafts. Surprisingly, the interest of each party, Muslims and Christians, for the swords of each other had not helped

for technical transfer[27]. Certainly the smiths were not ready to deliver their secrets to enemies and consequently, the production of crucible steel and the corresponding special forging process of blades were not transferred even in Al-Andalus. Dinnetz [49] says that preparation of crucible steel was possibly done in Seville, but the Muslim blades essentially came into Spain from the Maghreb.

A large part of the interest of European people for Damascus swords was certainly concentrated on their beautiful aspect.

Conclusions

The present paper was intentionally "single-aimed" towards gathering Western sources concerning the possible transfer of crucible steel technology or even more simply, the knowledge of the existence of special steels produced in Eastern countries. The number of Western testimonies is very small and partial, a situation totally different from the Arab world where a great number of precise descriptions have been published since the 9th century, which were unknown in Europe until the 18th century.

It appears finally that:

- No open technical transfer of crucible steel knowledge, especially on Wootz, took place between Eastern and Western countries, until the end of the 18th century.
- The existence of special oriental steel was known by a few specialists.
- Importation of *Damascus* or *Hindy steel* existed towards Europe maybe for special applications (engraving, mirrors, springs, etc.).
- A certain knowledge of cast-steel seemed to pre-exist to the 1740 patent of Huntsman on crucible steel.

An important question has not been approached, that is the exchanges between Indian Wootz producers and Europe. In fact, in the present paper, it has not been question of technical or commercial relations between Europe and the countries producing crucible steel, that is the metal delivered in ingots (loafs) or bars (already forged). However such commerce existed between India and the Persian Gulf, with batches arriving sometimes in Europe [19, 15, 49], but its importance is not clarified today.

The commercial transactions that have been identified in archives concern Dutch traders, through their Dutch East India Company, [13:20-24], which exported steel from India to south east Asia, Indonesia, and China, and also Portuguese [18, "on Wootz"] towards Africa. Yule explains that in 1691, steel was exported by Portuguese from India "... for sale on the African cost and to the Turks in the Red Sea." Even if it is not certain that all this iron and steel were crucible steel, as remarked by Bronson [13], no mention is made of Europe in these destinations. However, the exportation of iron from Venice towards the Near East is mentioned [5:42], at a time when Venice, Genoa, Pisa were the main traders in the Mediterranean Sea, after the end of the Crusades. Exportation of Wootz towards Japan has also been mentioned [29:12, 55].

In Europe, the nature of Wootz, and more generally of crucible steel was understood after technical and scientific studies, including travel reports such as that of Buchanan. This is, strictly speaking not a transfer but a kind of "discovery", because European scientists did not receive direct information from the Eastern metallurgists. The laboratory researches induced by studies on Wootz stimulated strongly the development of fine and alloyed steels, and especially of alloyed tool steels during the 19th century. The crucible steel process patented by Huntsman in 1740, might have been related to some "non-open knowledge" pre-existing in Europe on melted steel preparation, as remarked by Smith [16:24].

The medieval literature studied in the present paper, gives no useful information, except one or two words in hundreds of pages, showing that the existence of "iron from beyond the sea" was known, but without special interest in its properties. Even in Spain, after the eight centuries of the al-Andalus period, the current literature sometimes mentioned *alfinde* or *hindy* steel, without other precise description.

The analysis of the important contacts with Arabs at the frontiers of the Byzantine Empire might furnish other information, which has not been researched here.

New sources must then been found in archaeological research, in attentive observation of ancient pictures and also in the researches by historians on commercial and law registers [see Bronson and Coupland]. The phrase *spata india* quoted by Coupland from Latin documents of the French 9th century is a beautiful example.

The explanation of a strong barrier between two civilisations has been essentially attributed to a religious imperious blocking. However, the importance of Damascus steel for sword making has to be questioned. It can be found in non-documented papers, old or recent, that Crusaders feared particularly the Damascus swords, but we have found nothing to support this point of view in the medieval literature. The war successes were not firstly depending on the properties of swords, which were only a small part of armament of rich people, and many other armaments were largely used. This means that Western and Eastern arms, and especially swords, even if they were different in basic materials, were able to accomplish their mission that is to kill a maximum of people. We must also remember that the in-service properties of an object are certainly dependant on the properties of the base material, but much more on the shapes designed for a given application.

In 1740, crucible steel preparation was re-discovered in England, about one thousand years after it had been in common use in India and Muslim countries. The most surprising in this long empty story is the absence of curiosity and interest of European for foreign people, without doubt because they were enemies and/or often considered as inferior. The main interest of Western travellers concentrated on precious goods and exotic adventures. The know-how of smiths or other ordinary craftsmen was not taken into account by merchants who were mainly interested by financial profits.

In today dictionaries or education books, the situation is not fundamentally changed. Factual description of History is delivered: names of Kings, wars, etc. but practically no information is given on the evolution of techniques, and only precious objects are described. Furthermore, in scientific education books, the history of science and technology is largely neglected.

Finally, the answer to the question of transfer from India to Europe, directly or through the Muslim countries is: *no important direct transfer has been found in the Western sources described in the present paper* and we must remember that the numerous Arab papers published on crucible steel were "discovered" in Europe, only at the end of the 18th century.

Such a conclusion that few information has been found in chronicles and literature of Middle Age or Renaissance, could be considered as a failure. However, it is not the case: it is a constructive result because many sources have been questioned *in extenso*, and such a work on these texts is no more

necessary. When the answer to a question can be yes or no, *no* is as positive as *yes*!

We can propose that the "discovery" in Europe of the interest of Wootz, at the end of the 18th century means that the European industrial research was ready to use such a product at this time, and that it was not the case before.

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APPENDICES

J.B.TAVERNIER [11]. APPENDIX 1

Les Persans savent parfaitement bien damasquiner avec le vitriol, comme des sabres, des couteaux, et choses semblables mais la nature de l'acier dont ils se servent y contribue beaucoup, vu qu'ils n'en pourraient faire autant ni avec le leur, ni avec le nôtre. Cet acier s'apporte de Golconda, et c'est le seul qui se puisse bien damasquiner. Aussi est-il différent du nôtre, car quand on le met au feu pour lui donner sa trempe, il ne faut lui donner qu'une petit rougeur comme couleur de cerise, et au lieu de le tremper dans l'eau comme nous faisons, on ne fait que l'envelopper dans un linge mouillé, parce que si on lui donnait la même chaleur qu'au nôtre, il deviendrait si dur que dès qu'on le voudrait manier il se casserait comme du verre. On vend cet acier en pains gros comme nos pains d'un sou, et pour savoir s'il est bon et s'il n'y a point de fraude, on le coupe en deux, chaque morceau suffisant pour faire un sabre ; car il s'en trouve qui n'a pas été bien préparé, et qu'on ne saurait damasquiner. Un de ces pains d'acier, qui n'aura coûté à Golconda que la valeur de neuf ou dix sols, vaut quatre ou cinq abassis en Perse, et plus il va loin plus il devient cher. Car en Turquie on vend le pain jusqu'à trois piastres, et il en vient à Constantinople, à Smyrne, à Alep et à Damas où anciennement on le transportait le plus, quand le négoce des Indes se rendait au Caire par la mer Rouge. Mais aujourd'hui, autant que le roi de Golconda apporte de difficultés à laisser sortir de l'acier de son pays, autant le roi de Perse tâche d'empêcher qu'on n'enlève de celui qui

est entré dans son royaume. Je fais toutes ces remarques pour désabuser bien des gens qui croient que les sabres et couteaux qui nous viennent de Turquie se font d'acier de Damas ; ce qui est une erreur, parce que comme je l'ai dit, il n'y a point d'acier au monde que celui de Golconda qu'on puisse damasquiner sans que l'acier se mange comme le nôtre.

J. CHARDIN [12] **APPENDIX 2**

Les mines de fer sont dans l'Hyrcanie, dans la Médie septentrionale, au pays des Parthes et dans la Bactriane. Il y a du fer en abondance ; mais il n'est pas si doux que celui d'Angleterre. Les mines d'acier se trouvent dans les mêmes pays, et y produisent beaucoup ; car l'acier n'y vaut que sept sous la livre. Cet acier-là est si plein de soufre, qu'en jetant la limaille sur le feu, elle pétille comme de la poudre à canon. Il est fin, ayant le grain fort menu et délié, qualité qui, naturellement et sans artifice, le rend dur comme le diamant ; mais d'un autre côté, il est cassant comme le verre ; et comme les artisans persans ne lui savent pas bien donner la trempe, il n'y a pas moyen d'en faire des ressorts, ni des ouvrages déliés et délicats. Il prend pourtant une fort bonne trempe dans l'eau froide, ce qu'on fait, en l'enveloppant d'un linge mouillé, au lieu de le jeter dans une auge d'eau après qu'on l'a fait chauffer, sans le rougir tout à fait. Cet acier ne se peut point non plus allier avec le fer ; et si on lui donne le feu trop chaud, il se brûle, et devient comme de l'écume de charbon. On le mêle avec l'acier des Indes, qui est plus doux, quoiqu'il soit aussi fort plein de soufre, et qui est beaucoup plus estimé. Les Persans appellent l'une et l'autre sorte d'acier, poulad jauherder, acier ondé (*), qui est ce que nous disons acier de Damas, pour le distinguer d'avec l'acier de l'Europe. C'est de cet acier-là qu'ils font leurs belles lames damasquinées. Ils le fondent en pain rond, comme le creux de la main, et en petits bâtons carrés.

(*) *Poulad jauherder* ou *djauherdâr*; signifie littéralement *acier qui a des ondes*. Il est inutile, je crois, de remarquer que l'acier ne se trouve pas dans des mines, mais qu'on le prépare, en soumettant le fer doux à certaines opérations décrites dans les Traités de Métallurgie. Cette observation n'a pas échappé à l'auteur du *Nozahat-al-qeloûb*, d'où je vais extraire le paragraphe des mines de fer. *«Il y en a beaucoup, dit-il, dans le royaume de Qaban, ce qui lui fait donner le nom de forge. La montagne de Féçâs (ou Qaçâs) en*

Arabie, contient une mine de fer si bon, qu'on en fait de l'acier ; et les sabres nommés feçâcy (ou qaçâcy), sont renommés pour leur bonne trempe. Qathrah, dans la province de Thârmyn et Quazwyn renferment des mines de fer qui donnent de l'acier excellent. Les mines du canton de Khoùâf, du Qoubestân, de Faran et de la province de Fars sont aussi très renommées pour leur bon acier. Nous citerons encore celles de Kundjah, du Gulnyz, de l'Azerbâïdjân et de la montagne de Beler Koudjek ou Petit-Beler». Manuscrit persan, n° 127, page 269 . (L-s).

G.B.DELLA PORTA [14] APPENDIX 3

The "*Magiae naturalis*" was first published in Latin in four Books (1558). It was later enriched by many new items and expanded into twenty Books published in one volume (1584). Many translations have been made in the 16th century in different languages. The following English translation is from 1658.

In the 13th Book : "*Of tempering steel*", the following chapter is entitled:

Chapter IX

"How Damask Knives may be made":

Now while I set down these operations very pleasant, namely, how Damask Knives may be made to recover their marks that are worn out, and how the same marks may be made upon other knives. If then we would,

"Renew the waved marks of Damask Knives that are worn out"[a]*:*

Polish a Poniard, sword or knife, very well with Powder of Emril and Oil, and then cleanse it with chalk, that no part may be dark, but that it may glister all over. Then wet it all with juice of lemons mingled with Tanners water, that is made with Vitriol. For when it is dry, the marks will all be seen in their places, and wave as they did before. And if you will,

"Make marks with Damask Knives"[b]*:*

And that so accurately, that you can scarce know them from Damask Knives. Polish a knife very well, as I said, and scour it with chalk. Then stir with your hands, chalk mingled with water, and touching it with your fingers,

rub the edge of the sword that was polished, and you shall make the marks as you please. When you have done, dry them at the fire or the sun. Then you must have a water ready wherein Vitriol is dissolved, and smear that upon it. For when the chalk is gone, it will dye it with a black colour. After a little stay, wet it in water, and wash it off. Where the chalk was, there will be no stain; and you will be glad to see the success. You may with chalk make the waving lines running up and down. If anyone desires.

To draw forth Damask Steel for work[c]*:*

You may do it thus. For without art it is not to be done. Too much heat makes it crumble, and cold is stubborn. But by art, of broken swords, knives may be made very handsomely, and wheels and tables, that silver and gold wire are drawn through, and made even by, to be used for weaving. Put it gently to the fire, that it may grow hot to a golden colour, but put under the fire for ashes, Gip Calcined, and wet with water. For without Gip[d], when you hammer it, it will swell into bubbles[e], and will fly and come to be Dross and refuse.

Comments

a. In the 1st paragraph, "Renew...", it seems that Damask figures are incorporated in the metal.

b. In the 2nd paragraph, by "Make marks...", it is proposed to create figures by acid pickling.

c. In the 3rd paragraph, the description is that of forging a new blade from an old one with inlaid of silver or gold wires. Heating to a golden colour seems high because, if silver or gold wires have been drawn in the blade they might melt. But this may not be the case because the operation is aimed at forming a new blade. However, at a golden colour, that is more than 1000°C, it is clear that the steel used here is not Damascus steel, which must be forged at lower temperature.

d. Gip means gypsum.

e. Swelling into bubbles might signify that it is a "blister steel".

NB: In the first Latin edition of 1558, nothing can be found on the present paragraphs concerning steel treatment.

NOTES

1. The crucible steel technique was maintained in St-Etienne until 1965 for the production of high quality tool steels whereas the crucible steel technology had already been replaced by electric induction melting in the most important steel plants.

2. L-s : initials of Langlès who published the edition of 1811.

3. *Redsear* is generally translated by "hot-shortness", that means brittle at a red-colour temperature. In some cases this hot-shortness is related to the phosphorus or sulfur contents of the steel, for hypo-eutectoïd steels. However, the brittle behaviour of hyper-eutectoïd steels may have many other origins, for instance the pro-eutectoid carbides and the low melting point of inter-dendritic zones. However, the effect of phosphorus is predominant when the concentration is as high as 0.1wt% [20a], but such high phosphorus levels are not always found in the blades analysed by Zschokke [13:33, 20a].

4. Following Smith [16:24], *it can be concluded that cast steel was known in England before the Huntsman's patent of 1740.*

5. It would mean that after a first forging sequence, it is easier to work this steel when it has lost its extreme brittleness.

6. "Son Altesse Royale Monseigneur le Duc d'Orléans, a elle-même donné des ordres pour qu'on m'envoyât du Caire des aciers dont on fait les fameux sabres de damas. M. le Maire alors Consul du Caire s'est acquitté de son mieux de cette commission. Parmi les aciers que nous avons reçu de lui, & qu'il assure être les meilleurs, il y a un Pain, qu'on dit être de l'acier des Indes, & le plus estimé en Egypte. Il n'y a point d'Ouvrier à Paris qui vint à bout d'en forger un outil. Il ne soutient guère mieux le feu que la fonte de fer. Les autre aciers du Levant sont pour l'ordinaire difficiles à forger, mais moins que celui-ci"..

7. Diderot [21]: "Il ne faut pas oublier l'*acier* de Damas, si vanté par les sabres qu'on en faisait : mais il est inutile de s'étendre sur ces *aciers*, dont l'usage est moins ordinaire ici".

8. "... celuy de la Flandre, & en Italie, celui de Valcamonica au pays de Bresse, & hors la Chrestienté, celuy de Damas, de la Cecilia, ou Caraman, & le gemmino ou porfien dit Agiani, ..." [22].

9. Caraman was also the name of a small city near Toulouse (France), where the Cathares founded their so called "heretic" church in 1176, under the authority of a bishop coming from Constantinople. They were eliminated during a crusade ordered by the official Roman Catholic Church. Maybe, Caraman have been confusing for the French translator of Biringuccio in the 16th century.

10. The French "*brunisant - bruni*", which means *brown or burnished* has sometimes been translated in English by *brilliant, shining* and *polished.* In the present situation, it is a

mistake to translate *bruni* = *burnished* by polished or shining, because these adjectives refer here to a '*brown colour*'.

11. The battle is marvellous and great / The French strike with burnished spear / There you see so much dolour for people / So many men dead and wounded and stained with blood/ ... (trans. by myself).

12. He! Durendal, how beautiful and clear and white you are ! / Face to the sun how you shine and blaze/ ... (trans. by myself).

13. Smith [16:6]: Cassiodorus (6th century), secretary of the Ostrogoth King (Theodoric) wrote to the King of Vandals (Thrasamond) to thank him for a gift of swords, other objects and young people. The swords are qualified by : "...swords that will cut even trough armours... ; ... richer for their iron than for value of the gold ... [which embellishes them] ; ... polished brilliance...; ... their centres ... with worm-like markings...; the metal was interwoven ...; ... thoroughly polished, that it makes the gleam of the iron a very mirror...".

14. " ...blades with shining damascening, and sharpened edges..." (trans. by myself).

15. *Slovo* means *word* in Russian, representing a traditional story that has to be told orally, with the same signification as the *Song* of Roland.

16. Ancient name of people living in Ukraine and Russia.

17. The word *techa* comes from a *lapsus calami* (slip of the pen). The true word is *theca* (by moving the *h*). Here this word means: "scabbard"; in French :"fourreau" [23]. The meaning of the sentence is : "... *india* sword with scabbard decorated with silver...". The exact Latin word for *spata* is *spatha* (Greek root), representing a long sword.

18. That is: " in his testament".

19. "Avec la fin du IXème siècle, la fabrication des épées damassées cesse brusquement; à leur place une fabrication totalement différente aparaît, celle des épées tout en acier d'un métal assez homogène, sur lesquelles un des premiers fabricants a apposé sa marque: Ulfbert".

20. "Si les deux marges du sabre sont en acier tandis que la lame elle-même est en fer, le sabre est dit *mudakkar* (acéré) ce qui est le propre des sabres francs. Les Arabes affirment que leur fabrication est oeuvre de génies: ils résistent mieux aux coups que l'on porte avec eux, même pendant la froidure, au lieu que le sabre hindy se brise fréquemment lorsqu'il fait froid et se montre meilleur quand il fait chaud" (trans. Mercier 1924, 231) [49:76].

21. The same notion in found in Al-Tarsusi [3:127] : to prepare *fuladh* you must add "... drugs which dry its humidity ... and purify it of its defects, enough to make light get up from it and to reveal its internal structure". Further, the ingredients added upon melting, leaves and other materials, are called "medicines" in Indian records [50].

22. The classification of swords as a function of their geographical origins by Al-Kindi [1, 7] has perhaps a relation with the quality of the iron ore. This remark would reinforce the thesis of Verhoeven [20b] on the necessity of carbides former elements such as molybdenum, vanadium, etc., to help the apparition of a nice Damascus watering. This would be possible if people were always using primary iron for re-melting into crucible steel. However, when crucible steels were produced by re-melting nails or horseshoes, that is from recycled products, the same argument is difficult to maintain. The remark holds equally for Verhoeven and Al-Kindi. Maybe, the know-how of the smiths was the main reason of success for forging a nice Damascus blade?

23. The following information can be found in ordinary textbooks, see for instance [52].

24. For instance, the Venetian Marco Polo (13th century) travelled by earth to China and *sailed back* to Europe via the Persian Gulf.

25. "Ils résistent mieux aux coups que l'on porte avec eux, même pendant la froidure, au lieu que le sabre hindy se brise fréquemment lorsqu'il fait froid et se montre meilleur quand il fait chaud", (trans. Mercier 1924) [49, see above §4].

26. During the wars between Japan and China (1894-95) and later against Russia (1904-06), the swords broke frequently when the winter temperature was as low as – 30°C. [54].

27. Hammer Purgstall [7:72 n.1] says that the swords *souleimaniyé* "sont associées à celles des Francs qui très souvent sont honorées par les orientaux du nom de Djinns ou génies". It seems to be a quotation of Ibn Hodeil (14th century) (see above).

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