

IRON AND STEEL TECHNOLOGY IN HISPANO-ARABIC AND EARLY CASTILIAN WRITTEN SOURCES

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ABSTRACT - RESUMEN

This work comprises an evaluation of Hispano-Arabic and early Castilian literary evidence in relation to iron and steel technology. The study has led to significant conclusions concerning materials and processes involved in the ferrous metallurgy in al-Andalus and Castile during the time period *ca* 950-1400.

Este trabajo ha evaluado fuentes literarias hispano-árabes y castellanas medievales relativas a la tecnología de hierro y acero. El estudio ha rendido conclusiones significativas acerca de la metalurgia férrea en al-Andalus y Castilla durante el período *ca* 950-1400.

KEY WORDS - PALABRAS CLAVE

Hispano-Arabic and early Castilian literary evidence. Iron and steel technology. Crucible steel manufacture.

Fuentes literarias hispano-árabes y castellanas medievales. Metalurgia férrea. Producción de acero de crisol.

INTRODUCTION

While more comprehensive archaeometallurgical investigations on the iron and steel technology in other parts of the early Islamic world have been carried out, this is not the case for al-Andalus. Unfortunately, we can instead observe a few precipitated and unreferenced statements concerning the technological situation in this geographical area, along the lines of those countered by Bronson 1986, in his discussion on crucible steel production. The present work does not aspire to be exhaustive, but should rather be viewed as a first step towards the description of the iron and steel industry in medieval Spain.

For a discussion on the circumstances in regard to the ferrous metallurgical technology known and employed in medieval Spain, analytical investigations of archaeological material are necessary, applying methods such as microstructural and compositional analyses. We shall, however, also see that the particular terminology used by both Christian and Muslim authors in medieval Spain to describe iron and steel production, as well as the manufacture of specific items, give us certain indications in regard to material qualities and metallurgical processes. As a consequence of this, it is of crucial importance to also examine the written evidence in order to assess the general technological situation in al-Andalus during the time period under study.

The Andalusī literary sources provide us with valuable indications for the discussion of medieval iron and steel technology of medieval Spain, and further information is derived

from medieval Castilian written sources, which contributes to a further understanding of ferrous metallurgical technology in this geographical area.

TERMS FOR IRON AND STEEL QUALITIES

Iron

The two following passages, one Andalusī and the other Castilian, will here serve as an introduction to how iron was described in scientific treatises in mid-late 13th century Spain. The discussion of this paper will part from these two texts. It is important to see the terms in relation to each other within the separate passages, although each term will be evaluated separately during the course of this work.

In Arabic, the term *ḥadīd* is applied to describe iron-carbon alloys in a generic manner. The 13th century Andalusī herbalist from Málaga, Ibn al-Bayṭār (died 1248), provides us with a relatively clear classification of the three main kinds of iron. The note on *ḥadīd* in his *al-Jāmi' li-Mufradāt al-Adwiyya wa Aghdhiyya*, confirms earlier knowledge concerning the names for different iron qualities in Arabic, but it also gives additional clues which shall be compared with our knowledge gained from other treatises. Ibn al-Bayṭār refers to earlier authors after almost every sentence, which we should of course appreciate, but this makes the passage slightly disordered. We thus note that his information is of an entirely derivative nature. We find the following description (after the French translation by LeClerc):

There are many iron mines [in the world], and the quality of the divergent kinds of iron differ. One kind is by nature soft, and can by the addition of certain substances, become hard and stronger. There is one which, when plunged into water, becomes harder and more 'alive'. There is one that does not need to be plunged into water and yet it does not lack these properties. Each and every artisan needs iron. The world could not be without it, as it could not be without the fire, the water nor the salt. The rust of iron is the saffron of iron; and as to *dus*, it is the water of iron. The artificial *fūlādh* is made from *narmāhan* (Ibn al-Bayṭār 1877, 422).

This manner of ordering the different species of iron, carried out by an early Muslim author, has its counterpart also in a Christian treatise. In the *Lapidary* (ca 1278), a work commissioned for King Alfonso X of Castile, the Learned, who ruled between 1252-1284, we find additional explanatory remarks on the nature of different varieties of iron known in Castile. The translation provided here does not correspond exactly to that of correct modern English, but in order to stay as close to the original Castilian text as possible, thus ensuring that no details are lost, a direct translation into English is offered. The following account is made on the subject of this metal:

It is one of the best known stones used by man. There are those of weak and those of strong nature, and those that become stronger when they are plunged into water while hot; others, even though plunged into water while hot, they remain weak. There is iron to which, upon melting, medicaments are added by which it makes itself so strong that it cuts the other irons, and this the *Moors* call *alhinde*, and in some lands it is named *andanico*. There is another [kind of iron] which is not made artificially, but instead is strong in itself, thus cutting the weakest iron, and this one is called *azero* (Alfonso X 1980, 27).

Even though applying the term 'stone' (*piedra*), Alfonso X is without doubt discussing different iron-carbon alloys. The early lapidaries are generically terming minerals, metals and other materials, such as pearls, as 'stones'.

STEEL AND STEELED IRON

The medieval Castilian *azero/açero* refers to directly smelted steel, and the method used for its production would be the reduction of iron ores in a furnace using charcoal, in accordance with conclusions from earlier research carried out on medieval European steelmaking.

The only reference to *shabūrqān* in al-Andalus known so far is that under the entry *ḥadīd* in the work of Ibn al-Bayṭār. We are fortunate, for he gives both the Persian term, ie *shabūrqān*, and two related Arabic terms, *dakīr* and *aṣṭām* (Dozy 1881, I:653). In the Andalusī Arabic-Castilian dictionary by Alcalá from 1505, *dakīr* is translated to *azero*, ie 'steel'. Corriente's etymological research has shown that *dakīr* and its related term *mudhakkār* appear both in Hispano-Arabic prose and poetry (Corriente 1997, 193).

The Books of Astronomical Knowledge (*Libros del Saber de Astronomia*) from ca 1277, also these an assignment of Alfonso X, describe the making astronomical instruments of different kinds, as well as their applications. The second book, which treats the manufacture of astrolabes, was written by the learned Isaac ibn Sīd, also known as Rabiçag, of Toledo. When describing the making of the spherical astrolabe, the author gives instructions of how, and with what tools, lines should be cut into the surface of the finished brass globe. The lines needed to be neatly cut into the metal surface of the sphere by means of a two-legged compass especially made for the purpose. Describing one of the legs of the compass, he says;

...This movable shank should be of steel (*açero*), or of *Indian steel* (*alfinde*), so that you can cut into the brass with it (Alfonso X 1863, 118).

The steel quality *alfinde* noted in the quotation, will be dealt with under its heading further on in this paper. The term *mudhakkār* (male, masculine), is applied by al-Kindī to describe the 'natural steel', *shabūrqān* (al-Kindī 1952, 5). In the context of steelworking, *mud* in the Andalusī Arabic vocabulary additionally describes a metallurgical technique, which was applied in the manufacture of iron-steel composites. Writing in Naṣrid Granada in the 14th century, Ibn Hudhayl affirms that the term has this connotation, when describing the difference between *Frankish* blades and those made of *Indian steel* (from the French translation by Mercier):

If the two edges are made of steel while the blade itself is made of iron the sword is said to be *mudhakkār*, which is the case with *Frankish* swords. The Arabs state that their manufacture is the work of *jinns*: they withstand better the blows delivered with them also during cold weather, not like the *hindī* blade that often breaks when the weather is cold and shows itself better when it is warm.

Here we can note that Ibn Hudhayl had detailed knowledge concerning the method of welding steel edges onto a softer iron core, in order to achieve a more flexible blade, and perhaps also to economise with the steel. This type of blade construction was common in other parts of Europe (Tylecote and Gilmour 1986), and Ibn Hudhayl's familiarity with its manufacture most probably indicates its employment within or in the proximities of the *Taifa* of Granada. It should be added here, that for the Muslim inhabitants of al-Andalus, *Franks* would primarily indicate Christians in the Iberian peninsula, even if other Europeans were also identified by this term.

The Castilian evidence examined here also give information concerning artefacts consisting of both iron and steel, but the sources are unfortunately not as specific as the Andalusī in providing information of the technique by which the iron was steeled. Before making any statements we shall consider another sentence from the *The Books of Astronomical Knowledge*:

...Take a rod of *Indian steel* (*alfinde*) or of steeled iron (*fierro calçado con acero*), and make a very sharp point (Alfonso X 1863, 129).

We can note here that both *Indian steel* (which again will be treated under its proper heading further on) and steeled iron could be used for the same technical purpose. Instead of employing the term '*azero/acero*', '*fierro calçado con acero*' is used, the latter terminology possibly describing an additional material quality. In modern Castilian, the verb *calzar* literally means to coat or to cover, and here it appears to be used to describe the action of giving an iron object a steel surface or edge. The most common method for steeling iron, which is also documented in archaeological contexts, appears to have been the forge-welding of a piece of steel onto a piece of iron or between two iron laminas, using, for example, quartz as flux in order to keep the surfaces to be joined free of oxides, and to liquidise the oxides already present there. This would also give the object a hardenable material where desired, for example the edge of a tool. Microstructural analyses of 9th-11th century knife blades from the Hispano-Islamic city of Vascos, close to Toledo, has indeed yielded evidence for the lamination technique, where two of the blades had a steel piece, forming the edge, welded in between two pieces of iron. Furthermore, bainitic structures in the edge of one of the blades affirmed that the implement had been quench-hardened and subsequently tempered (Karlsson, forthcoming).

The other possible technique for steeling iron is the surface carburising, or case hardening, of an iron object, most likely in a receptacle of some sort together with carboniferous material, and placed in a hearth or forge. This would give a hardenable surface layer of steel, for example, in the edge of a knife. As the description in the text of Alfonso X concerns a fine rod for incising lines in a brass surface, it seems less likely that a steel tip or point would have been welded onto an iron rod, because of the small size of the object. It is hard and awkward to forge-weld smaller objects, as it is difficult to control the welding temperatures the smaller the object. The heating of a minute steel piece could easily destroy the material by burning, as in contact with air a strong oxidising reaction takes place. But then, the question is why ordinary medium-carbon steel was not used, which would have been easier than both welding and surface carburisation. It is seen as possible, though, that steeled iron implies surface carburising of the incising tool. Fell and Salter (1998) found examples of Early Iron Age axeheads from England with carburised surfaces, even though they mention the possibility of this being the result of an accidental process in the hearth. It is not possible, however, to conclude anything further from the above examined information.

No applications of the Arabic term *aṣṭām* in the Andalusī sources have been found, other than that by Ibn al-Bayṭār. Dozy also only mentions Ibn al-Bayṭār's reference, and Lane (1984) does not have any entry for the term. However, there are similar terms, such as *saṭḥ*, *suṭūḥ* and *aṣṭaḥ*, meaning 'surface'. The related verb *niṣaṭāḥ/ṣaṭāḥt*, as indicated by de Alcalá, bears the significance 'to floor' or 'to pave' (Corriente 1997, 251), and this possibly indicates that *aṣṭām* is an additional term for the Arabic *mudhakkar*, or the Castilian *hierro calçado con acero*, ie 'steel-clad iron'. Before we can accept this hypothesis, though, it is necessary to encounter further evidence for the use of the term in similar contexts.

As a concluding remark on 'steel', we have an unusual opportunity to directly derive its counterparts in three languages, namely Persian, Arabic and Castilian, which is also a further example of the complex linguistic, cultural and technological environment that Spain represented during the time period under study. Ibn al-Bayṭār's reference to the Persian *shabūrqān* shows that its Arabic synonym *dakīr*. The early Andalusī Arabic-Castilian dictionaries indicate that *dakīr* signifies *azero*, and the reference by Alfonso X to *azero* as deriving from a direct smelting process, shows that directly smelted steel equals the Persian *shaburqan* and the Arabic *dakīr*.

Indian steel

Earlier discussions on the subject of Islamic ferrous metallurgy has shown that the term Indian, *ie al-hind* and variants such as *muhammad*, *hindiyya*, and *hinduwānī* refer to the steel quality (Yule and Cordier 1975, 93), and furthermore, that its making involved a crucible process rather than the actual geographical origin (Bronson 1986; Lang et al. 1998). While assessing the informative value of Hispano-Islamic poetry from the eleventh century, Pérès perceived that the term *Indian* applied to the quality of blades, implying that the material was produced in Spain. He thought, however, that it was employed only to describe blades of excellent quality, without entering the discussion of crucible steel manufacture (Pérès 1990, 355).

The reference to the earliest use of *Indian steel* in al-Andalus is made by Ibn al-Khaṭīb, writing in 13th century Granada. This historian records that during the attack on Barcelona in 985, the soldiers of al-Manṣūr, effective ruler of the Cordoba Caliphate at the end of the tenth century, were equipped with armour pieces of *Indian steel*, *qarāmīd al-hind*, to protect their arms against the sword blows of the *Franks* (Vallvé Bermejo 1980, 213). The singular for this term is *qarmīd*, meaning piece of armour (Alcalá 1988). The entry for this word in Corriente's Andalusī Arabic dictionary (1997, 425) indicates that the word also applies to roof tiles, for which reason we can assume that this particular armour, supposedly then of curved and tile-like shape, was made to fit arms, which is confirmed by Ibn al-Khaṭīb, and perhaps also legs.

Ibn al-Khaṭīb further notes that, during the reign of al-Manṣūr in the 10th century, there were two important workshops for the production of arms and armour at Cordoba and at Madīna al-Zahrā'. The one at Cordoba was supervised by Abū al-Abbās al-Bāghdadī, and the other, at the caliphal city of Madīna al-Zahrā', was run by Ṭalḥa al-Ṣaqlabī. These two industrial centres had to produce 13000 shields and 12000 Arab and Turkish bows altogether annually, the manufacture being split equally between the two. The monthly production of arrowheads reached the impressive number of 20000 (Vallvé Bermejo 1980, 214). Considering the great capacity for arms and armour production at Cordoba, which clearly reflects the war capacity of the Caliphate, it seems most likely that the armour of *Indian steel* worn by al-Manṣūr's soldiers, mentioned earlier, was produced in the workshops at Cordoba.

In the biography of Yūsuf ibn Tāshfīn (died 1106), mostly based on the report written by al-Bayāsī (died 1255), al-Khallikān refers to letters sent to the Christian kings of the peninsula by the Abbaid ruler in Seville, Mut'amid, informing them of the danger of further advances into Muslim territories. After this, when Mut'amid once again felt the impact of the Christian attacks, he felt forced to ask the fanatical Yūsuf ibn Tāshfīn and his Almoravid troops for help against the Christian king, Alfonso IV, in 1086. Yūsuf first intervened with his main power, a bodyguard consisting of 4000 mounted black warriors, at the battle of al-Zallāqa, near Badajoz. According to al-Khallikān, the bodyguard of Yūsuf used swords of *Indian steel* (*suyūf al-hind*), together with shields and javelins, in this battle (Hoffmann 1995, 243-8). We do not know whether all of the warriors used such swords, as this is not specified, but what is far more important than their numbers, is to remark that they were in use. It seems likely that the weaponry was brought from Almoravid North Africa, as the troops went directly from Algeciras to the battle. The swords were thus brought over the Strait of Gibraltar, and it appears most likely that they were also manufactured in North Africa. There is of course a possibility that the blades had been previously imported, but on the other hand, it must have been crucial for any ruler to provide his standing force with weapons from their regular armoury, without having to depend on other sources for war equipment. The making of *Indian steel* in this area, more specifically in Ceuta, is furthermore confirmed by a Castilian source from the latter part of the 13th century, and this will be dealt with further on under this heading together with other Castilian written evidence for this steel quality, for reasons of consistency.

Among the arms and armour mentioned in a poem by Ibn al-Labbāna (died 1113), who was tied to the Abbadid court of Mut'amid at Seville, a sword is referred to as *sayf muhan-nad*. Pérès points out that the poet appears to have deliberately grouped the different weapons and armour together (Pérès 1990, 355). Whichever the case might be, it is clear that the author had a thorough knowledge of weaponry, describing them and their materials in detail.

The Almoravid poet Abū Bakr al-Ṣayrafī, writing at the beginning of the twelfth century, provides us with some information concerning his view of the quality of *Indian steel*. After the Almoravids lost a battle against the Christians, the poet permitted himself to give advice on changes in tactics and weaponry that he thought appropriate. Among other things, he suggested that thin-bladed *hinduwānī* swords should be used, as they were sharper than other swords, thus piercing the heavy armour worn by the Christian soldiers more easily (Pérès 1990, 355).

There is a passage in the geographical treatise (*Kitāb al-Ja'rāfiyya*) by al-Zuhrī, which is of outmost relevance to the discussion of indigenous production of {*al-hind*} in al-Andalus, as it is the first reference to its making at a specific site, *ie* Seville. Hadj-Sadok, who edited and commented al-Zuhrī's work, finds it most likely that the author was Andalusī (al-Zuhrī 1968, 24). The piece of information provided by al-Zuhrī, seems to be his own annotation, as he does not refer to an earlier author, while other parts of the treatise are attributed to earlier writers. Thus, when al-Zuhrī wrote, *ie* by the late 12th century, *Indian steel* or *al-hind*, was manufactured in the city of Seville (al-Zuhrī 1968, 92).

An author contemporaneous with al-Zuhrī, was the agronomist Ibn al-'Awwām, active in Seville during the latter part of the 12th century, and possibly also in the beginning of the 13th century. In his Book of Agriculture (*Kitāb al-Filāḥa*), the author discusses remedies for curing wounded or sick animals. Ibn al-'Awwām mentions a number of surgical instruments and their making, and recommends that a specific instrument should be made of *ḥadīd hindī*, and that it had to be very sharp (Ibn al-'Awwām 1988 II, 582). As this instrument was intended for surgery close to eye of the animal, a task calling for high precision, this again indicates that early authors attributed high edge qualities to *Indian steel*.

Mirrors were manufactured from steel in early Islamic times, and literary evidence of their existence in al-Andalus is provided by contemporaneous writers. The Andalusī traveller Ibn Jubayr (1145-1219) states, when discussing a mineral, that its properties were 'very black and very shiny, of a kind that reflects the image of people entirely, as if it was a recently polished *Indian steel* mirror (*mirāt hindīyya*)'. Ibn al-Khaṭīb compares the appearance of the Granada sky one day with a mirror, saying; 'When we arrived in Granada, the sky was polished like a double-edged sword, as clear as an *Indian steel* mirror (*mirāt al-hind*) (Dozy and Engelmann 1869, 142-3)'. We here see that when intending to describe a great degree of clearness, the Andalusī authors relate to the polished surface of *Indian steel* mirrors.

Marco Polo notes at the end of the 13th century, that in Kuh-banān in Kirmān, 'there is much iron and steel and *ondanique*, and they make steel mirrors of great size and beauty' (Yule and Cordier 1975 I, 125). The authors note that Marco Polo consequently uses the expression 'steel and *ondanique*', which, according to them most likely indicates that this was his perception of the Persian *Pūlād-i-Hundwānī*, *ie* *Indian steel* (Yule and Cordier 1975 I, 93).

Earlier linguistic research has shown that the Arabic term *al-hind*, as applying to steel, found its way into the medieval Castilian vocabulary as one of the variations *alfinde*, *al-hinde*, *alhynde* and *alinde* (Dozy and Engelmann 1869; Casares 1915; Corriente 1997). The mentioned authors reflected on the significance of the Castilian Arabism *alhinde*, and its application in medieval Castilian literature, and their common conclusion has been that the significance of the term was exclusively that of 'steel' or 'steel imported from India', without further explanation.

The first question to arise should be why the Arabic term was ever employed for the alloy, if the plain significance was that of 'steel'. It is worth noting that the conventional medieval Castilian word for steel, *ie azero/açero*, which derives from the Latin *Aciarium*, was not adopted to describe *al-hind/Indian steel*. One would perhaps have expected *azero/açero* together with an implication to the geographical origin of the material, *ie India*. It is thus concluded here, that the Arabic term described a steel quality for which there was no corresponding term in Castilian, *ie crucible steel*. Subsequently, this would indicate that this kind of steel was introduced to the Iberian peninsula during Islamic rule, before the Christian conquest.

As we have seen, it is attested in the *Lapidary* that *alhinde* is steel resulting from a secondary process, by the reference to certain substances that needed to be added to the iron during a melting operation, which produced a very kind of steel. It is significant that reference is made to the great hardness of this steel, by stating that it cuts all other kinds of iron. The veracity of the assertion in regard to the material hardness is strengthened both by early Islamic writings, as we have seen earlier. The early sources especially describe blades of *Indian steel* as being very hard, brittle and prone to breaking, often in cold weather. Moreover, it should be noted, that the name for this steel, that is, *alhinde*, is derived from the word generally used by the *Moors*, apart from the already attested use of the term in the Arabic scientific and geographical treatises already mentioned. As we have noted earlier, in the *Books of Astronomical Knowledge*, *alfinde* was applied in the manufacture of cutting implements used for engraving the brass surfaces of astronomical instruments.

Three early Castilian texts were compiled by Father Sebastián of Vergara in the 18th century, in the work named *The Life of Saint Domingo of Silos (La Vida de Santo Domingo de Silos)*. One of the texts, called *The Miracles of Saint Domingo of Silos*, which was written in the 13th century by Pero Marín (died ca 1293), should be drawn to our attention. A part of this text treats the misfortune of a certain Domingo Bono during the year 1285. This Christian was captured by a band of slave-traders and sold twice, ending up in Ceuta, which is now Spanish territory on the North African coast bordering Morocco, as a slave working for a Muslim master. The passage is concise and clear, and it provides us with details such as precise dates and locations, and even the prices the man was sold for. The mentioned meticulousness underlines the informative value of the passage. The indication of the location for this steel industry, Ceuta, is moreover significant, as it is the first known reference to *Indian steel* being made there. The text is therefore translated to English and quoted here (Castilian text edited by Karl-Heinz Anton 1988):

He was put in strong irons [by the *Moors*], and at daytime he made *alhynde*, which is of such importance for warring, being a very strong steel from which they forge swords and *azagayas*. At nighttime he was kept in quarters deep underground (Marín 1988, 136-7).

In this text, it is possible to remark a description which obviously refers to the process of making of *Indian steel*, and subsequently that it was used to produce weapons such as swords and throwing-spears. As a note, it should be mentioned that according the *Diccionario de la Real Academia Española* (1992), the Castilian *azagaya*, meaning throwing-spear, stems from the Berber *al-zaghāyya*. The words '*alhynde*' being a very strong steel from which they make swords and *azagayas*' is evidently an allusion to the fact that the *Moors* made and worked this material. This is also confirmed in the *Lapidary* of Alfonso X ca 1278, which has already been dealt with earlier on in this paper, and this seems to indicate that Christians did not produce the material. It is however important to stress that the Christians were aware of the qualities of this 'very strong steel', even though it might have been that its manufacture was in the hands of Muslim steelmakers.

Moreover, Domingo Bono seems to have been involved only in the manufacture of the steel, and not in the actual making of objects. This implies that slave labour was used, at least by the Muslims of al-Andalus, for heavy work such as iron and steelmaking. We can assume that specialised smiths were involved in the manufacture of weapons and tools, as this would require more experience.

The reference to *andanico* in the *Lapidary*, as being an additional term for alhinde, proves to be very valuable. Marco Polo, travelling in Central Asia at the end of the 13th century, contemporaneously to the writing of the *Lapidary*, remarks on the *ondanique* of Kirmān in present-day Iran, and in Chingintalas, a region to the north of Tibet according to Yule and Cordier (1975). The *Lapidary* conveniently affirms that *andanico* in fact is synonymous with *Indian steel*. Moreover, the text indicates that the material was known also under this name in the Christian society of medieval Spain.

Fūlādh

For the Islamic authors, *Indian steel* was synonymous with crucible steel, even if the term *al-hind*, with its variants, was not the only term applied for this material throughout the Islamic world. Renowned Near and Middle Eastern Muslim authors, such as al-Kindī, al-Birūnī and al-Ṭarsūsī, refer to steel manufactured by crucible processes applying the term *fūlādh*. al-Kindī describes the manufacture of *fūlādh*, saying;

As for the iron which is not mined, it is *fūlādh*, which means purified. It is made from mined iron by throwing onto it during the melting something which purifies it, and makes its softness strength, so that it becomes very pliable, accepts quenching and its *damask* [*firind*] appears in it (Allan 1979, 75).

The following statement by al-Ṭarsūsī illustrates the early Islamic view on *fūlādh* adequately:

As to things which are made from these minerals [iron ores], the *fūlādh* is the deadliest and most powerful, the noblest and the most eminent product (Cahen 1948, 127).

In his treatise, *Tabṣīrat al-Arbāb al-Albāb*, which al-Ṭarsūsī wrote around 1187 AD for the Ayyūbid conqueror of Jerusalem, Salādh al-Dīn (1138-93), there are descriptions for the making of different kinds of *fūlādh*. As an example, al-Ṭarsūsī describes the making of *fūlādh Sulaymānī*, for the making of blades with the same name, in the following manner: Twenty *dirhams* of cultivated *myrobalans*, seven *dirhams* of manganese and five *dirhams* of *scammony* should be ground together well. This mixture should then be added to three *raṭl* of *shabūr qān* in a crucible, which should be sealed with a clay lid pierced by a hole, permitting the observation of the crucible charge during the melting operation. When the ingredients had liquidised completely, the crucible was left to cool, and the ingot was subsequently extracted (Rāghib 1997, 68).

It is not likely that the steelmakers themselves were following recipes, but rather that they had life-long experience of the procedures. Therefore, the process, on which the above recipe is based, was most likely employed by the steelmakers in Ayyūbid Egypt or Syria, who would then have provided al-Ṭarsūsī with this information. As we have no reason to doubt that crucible steel in fact was produced in mid and late-12th century Egypt, al-Ṭarsūsī's description of such a process is the closest and therefore the most relevant available parallel, both in time and space, to the discussion of crucible steels in medieval Spain.

An early reference to *fūlādh* by an Andalusī author dates to the end of the tenth century, when Idrīs al-Yamānī in a poem describes that certain shields made of hardened leather were capable of withstanding, and even cracking, the purest *fūlādh*. The fact that the poet comments on the breaking of *fūlādh* blades, further indicates that these were more fragile than

other blades. al-Kindī uses the term purification in the context of crucible steelmaking, applied to the action of melting certain matters, presumably the carboniferous material, together with the iron (Allan 1979, 74).

Ibn Sa'īd describes the steelmaking industry in Seville during the first half of the 13th century as manufacturing *fūlādh*, stating that the quality of this material was excellent (al-Maqqarī 1949, 202). As he, when describing other centres of steelmaking such as Almeria and Murcia, uses the term *ḥadīd*, this perhaps indicates that the *fūlādh* produced in Seville was of higher quality, and that he therefore named it applying its specific term. Another possibility is that Seville was the main centre for the production of *fūlādh* in al-Andalus under Almohad rule, as it was the Andalusī capital and most important town during this time period, and that the author for this reason disregarded minor centres producing crucible steel. As we have seen, al-Zuhrī described the production of steel in Seville already in the late 12th century, using the term *al-hind*, and this is seen as an indication to the continuity in the manufacture of crucible steel. When the city was taken by Ferdinand III of Castile in 1248, this event marked the peak of Castilian expansion, and at present, we cannot be certain whether the manufacture of *Indian steel* continued after the Christian conquest. It is relevant, however, that one of the possessions left by King Peter I of Castile to his son in his will, was a *Moorish* sword that the king had had made sword for himself in a Sevillian workshop, sometime before his death in 1362 (Ferrandis Torres 1943, 147), which likely implies that Muslim or converted Muslim bladesmiths were still working in the city in the middle of the 14th century.

Watered steel

Knowledge of watered steel existed in al-Andalus as well, this indicated by a few Andalusī references to the material. However, there is as yet no firm literary evidence indicating the production of watered steel in Spain. Ibn Sa'īd, as we have seen earlier, mentions that *fūlādh* was produced in Seville during the first part of the 13th century, but it is not clear whether he specifically refers to blade patterns, as the term used in connection with *fūlādh*, *daqā'iq*, has an ambiguous significance. The Andalusī Arabic *daqā'iq/daqīq* does according to Corriente (1997, 181) mean [fine-ground] grain, which could support Zakī's interpretation of the passage (Zakī 1955, 295), who was in no doubt that the term indicated watering. However, Gayangos reads 'sharp-edged' (al-Maqqarī 1840, 94), for which Lane (1984) provides an example. According to the latter, *sayf daqīq al-madrībī* means, 'a sword thin in the edge, or in the part next to the point' (Lane 1984 I, 896). Earlier Middle Eastern authorities describe watering either as *jawhar* or *firind*. Ibn Hudhayl in 14th century Granada, discusses the characteristics of blades with watering applying the term *jawhar*, and several allusions to patterns and lustre of blades can be found in the poems related to arms and armour quoted by him (Ibn Hudhayl 1924, 232). It should be mentioned here, that Ibn Hudhayl describes the lustre (*utur*) appearing in the surfaces of, apparently, polished blades, when these were flexed (Ibn Hudhayl 1924, 232). This means that not all references to 'lustrous' in connection with blades necessarily imply watered steel.

If Zakī's interpretation is right, *daqā'iq/daqīq* in this context would be an additional term designated for describing the watering. Before we can draw any other conclusions in relation to this passage, further written or archaeological evidence has to come to light.

Al-Birūnī noted when discussing crucible steel production, that the *fūlādh* could be either with or without watering (Allan 1979, 75). Regardless of whether *fūlādh* manufactured in Spain had watering or not, the international arms trade, which already in early Islamic times spanned from China to the Iberian peninsula, passing either over Bašra and the Gulf or through Egypt and the Red Sea (Elgood 1993, 104), surely brought such blades to the peninsula at an early date. Furthermore, Arabs had knowledge of and used watered steel blades already in pre-

Islamic times, as indicated in a poem by Imru al-Qays (ca 450 AD), where he describes the watering of a certain sword as 'appearing to be like tracks of ants'. His contemporary Aws b. Hajar declared, that 'a blade of that kind is like a pond with wavy streaks caused by the wind' (al-Hassan and Hill 1986, 255). It is therefore quite probable that the first Arabs who settled in the Iberian peninsula already in the 8th century, brought such blades.

Cast iron

Ibn al-Bayṭār states that *dūṣ* is the water of iron (*ma' al-ḥadīd*), and that some authors believe it to be iron dross, while others that is the water in which one quenches hot steel (Dozy 1881 I, 653). Allan (1979) concluded that *dūṣ* in some cases likely describes cast iron, but as no clear information in relation to this term has yet been offered by the Andalusī literary sources, it is not possible to tie in with Allan's discussion. Therefore, there will be no attempt to deal with the term in the present work.

CONCLUDING REMARKS

Based on the examination of early written sources, the discussion of this paper has produced evidence for the scholarly and practical knowledge of iron and steel technology, as well as uses for different ferrous alloys in al-Andalus and Castile between ca 950-1400. The Iberian peninsula was, during the time period ca 700-1500 very important in terms of technological overlap. There are both Andalusī and Castilian literary references to the employment of iron and steel technology similar to that noted in the rest of Europe, as expected. This includes the direct smelting of steel, and the manufacture of iron-steel composites. Additionally, written sources have provided information of a character that has facilitated the interpretation of Persian and Arabic terms for material qualities.

Some conclusions have been made with regard to terms for iron and steel qualities in the above mentioned written sources. *Ḥadīd* is the Arabic generic term for iron-carbon alloys, and its Castilian counterpart is *hierro/fierro*. The only occurrence of *shabūrḡān* known so far is that by Ibn al-Bayṭār in the 13th century, but as he mentions its Arabic counterparts, this has led to the conclusion that the significance is that of directly smelted steel, *ie* the Castilian *azero/açero*.

The research for this paper has yielded evidence highly relevant to the discussion of crucible steel (*ie Indian steel*) manufacture in the early Islamic world. It is viewed as most likely, that objects made of crucible steel were introduced to the Iberian peninsula with the Islamic conquest, *ie* between ca 711-720, as the material was widespread in the Near and Middle East long before the dawn of Islam. It is possible, in fact, that the material reached the peninsula even before the Islamic conquest, by means of long-distance trade. We should however be cautious as to claim indigenous crucible steel manufacture in Iberian peninsula already in the 8th century, as there is no literary or archaeological evidence to support this.

Even though the use of *Indian steel* armour pieces is indicated already in the late 10th century in al-Andalus, it is first in late 12th century Seville, the Andalusī capital of the Almohads, that the manufacture of this alloy is confirmed, by the Andalusī author al-Zuhri. We can further note continuity in this industry, as Ibn Sa'īd refers to the production of *fūlādh* in the same city, in the early to mid-13th century. Some forty years after Seville had fallen to the Christians, an event taking place in 1248, a Castilian source provides evidence for the production of *Indian steel* or *alhinde* in Ceuta, North Africa, just across the Strait of Gibraltar from the mainland of present Spain. The written evidence here examined pin-point two centres of *Indian steel* manufacture, *ie* Seville and Ceuta, but these were most likely not the only centres for this industry in al-Andalus.

Crucible steel was thus manufactured by Muslims in al-Andalus, and Christians on the Iberian peninsula were also familiar with this material, even though it is not yet clear whether this material was produced and/or worked by them as well. The application of *Indian steel* in al-Andalus is noted in the manufacture of weapons, specialised cutting tools, surgical instruments and mirrors.

The examination of written evidence, indicates that authors of early works on iron and steel did most likely not have personal practical knowledge of the materials and processes they were describing, and more often than not, their information was partly derived from other, earlier authors. Thus, the fact that a treatise was written at a certain locality, does not necessarily imply that the described technology existed there. The significance of this is that practical metallurgical knowledge did not travel with treatises. On the other hand, references to sites, employing specific terms for describing the iron alloys produced, give indications with regard to metallurgical processes applied at a certain site.

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