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Manufacture of the High Quality Carbon Iron/Steel in India in the Medieval Period

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Abstract

The manufacturing of the high quality Carbon Iron or Steel in India has attracted the attention of historians, archaeologists and scientists. Each one has delt the subject in their own way. In the present article an attempt has been made to understand the subject in total perspective. The scope of the article is limited to Medieval India. The survey of the literature reveals that Indian Steel was very popular during the medieval period of history.

Keywords: Crucible; Indian Steel; Pulad; Damascus Blades; Madras Wootz; Ingots**.**

The cast crucible steal that is also know as Wootz, which though a German term, is supposed to be a Dravidian word' derived from UKKA, which in Kannada means 'Steel'. Probably the first literary reference to steel , which is available so for, is a Greek source of 4th century B.C. According to it, the presents offered to Alexander by the Malavas and their allies included a hundred 'Talents' of white iron (Ferrum Candidum). This is generally taken to mean 'steel'. Besides the Greek references, the evidence of Meharauali- Delhi Pillar (300 to 500 A.D), Konark Temple beams-Orissa (900 A.D.) and the Dar pillar-Indore, Madhya Pradesh (1000 A.D.) prove the continuity of excellent iron manufacturing in India. During the long span of ancient Indian history, Iron was made and extensively used to make ploughs, bullock cart rims, small structural items and several other tools and implements for a variety of applications.

In view of Juha Perttula the production of Wootz Damascus steel started in 500 A.D. or earlier and the last highest quality blades were made perhaps around 1750 A.D. There are references which prove the antiquity of steel before the Christ in India. W. H. Schoff (The Periplus of the Erythreaean Sea) has identified Ferrum Candidum with fine steel. It was used for swords and mirrors for which India was famous. Even Macro Polo refers to iron and ondanique in the markets of Kerman, and Yue derives it from "hundwaniy" i.e. Hindustani or Indian Steel (Chakarbortty, S.K., 1931 p. 74-75). Royle — a famous writer of Antiquity of Hindu Medicine also remarks: "Working in metal they have long been 'famous for: their steel acquired so great celebrity at an early period, as to have passed into a proverb among the Persians, Where foulade, hind indicated steel of the best quality."

The present article's scope is limited to Medieval period of Indian history. Therefore, it will be worth to examine the term Medieval history. The term Medieval India is an anathema to some historians. Earlier, the medieval period of Indian history was supposed to begin from the downfall of Harsha, the middle of the 7th century. Some of the historians prefer 1000 A.D. as cut off point because the invasions of Muhammad of Gazni began from 999 A.D. But now majority of historians agree that medieval history begins from 1300 AD when the Muslim rule was firmly established over a large part of the country save south India and it can therefore be provided 1300-1800 A.D. as the time bracket (Dhavalikar, M.K., 1999, p. 114-115).

Historically, Indian iron gained importance during the middle of the first millennium A.D. when

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Indian iron suddenly started to appear as a standard ingredient of the swords used by the inhabitants of the Arabian Penisula. The early scientific studies of swords and steel began in eight century. The works of Jabir-ibn Hayyan, Al-Kindi, Al-Biruni and Murda al-Tarsusi are important for this purpose. These All Islamic writers categorized the Indian weapons in the third place. Commercially Indian iron took prominence in twelfth centuries A.D. The business correspondence between the middle-east based Jewish merchants and their India based colleagues or agents provide the evidence of it. Various Islamic sources clearly indicate that during the whole of the middle-ages Indians were making high quality steel and they were also shipping iron and steel to other countries also.

AL-Sharif Al-Idrisi – a known writer of 12th century A.D. describes the excellence of Indians in iron making. He describes in his narration that mountains of Kabul have numerous iron mines. These are well known and very profitable. Their iron is extremely sharp and beautiful. It is of a grey colour and veined — it becomes very sharp. In an another instance Idrisi describes that the Indians are very good at making various compounds of mixtures of substances with the help of which they melt the malleable iron, it then turns into Indian iron, and is called after India. There (in India) are workshops where swords are manufactured, and their craftsmen make excellent ones surpassing those made by other peoples. In the same way, the Sindhi, Sarandibe and Baynimani iron vie with one another for superiority as regards the climate of the place, skill in industry, the method of melting and stamping and beauty in polishing and scouring. But no iron is comparable to the Indian one in sharpness. This is a well known fact, and no one can deny its superiority (Idrisi, 1960 pp. 23,67).

In the commentary on Idrisi's book 'India and the neighbouring territories', S. Maqbul Ahmad writes, 'The use of Indian iron in the manufacture of goods of fine quality is often referred to in Arabic literature. In a long discourse on iron, Biruni describes the different qualities of iron, their properties, and the use of certain varieties in the manufacture of swords in some countries. He especially describes the various type of iron and other compounds used in the manufacture of swords and daggers in India (Ahmad, S.M., 1960, pp 132). It is clear from the above description that Indian iron was widely popular in Arab world during the 12th century A.D.

The Indian high quality carbon iron was known to the oriental world and even presently it is called with various names e.g. Indian Wootz, Central Asian Pulad, Bulat, Oriental Damascus and Crucible Steel. It has fascinated craftsmen, scientists and layman for almost two thousand years. Even today, in the first decade of the 21st country, it is still amazing the scientists and archaeologist. In daily paper 'Chicago Tribune' of United States Jeremy Manier wrote on 26th August, 2001, the following:

"This technology has been lost for about 200 years", said Ben Bronson, Curator of Asian Anthropology at the Field Museum of Natural History in Chicago and an expert on Damascus steel "A real driving force in the development of modern steels was the attempt to replicate cencient Indian and Middle Eastern steels". "Even description of the metal date at least to the 1500s, but many scholars believe Muslims from Egypt to India used it for hundreds of years before that. Western traders encountered the steel in the Syrian capital of Damascus though there is no evidence, it was ever made there." "Yet even their rivals concede Verhoeven and Pendray are the first to recapture both the external beauty and microscopic structure of genuine Damascus Blades" (JERMY MANIER, Chicago Tribune, 26 August 2001, Times Union—2007, Factiva). Europeans encountered with the iron only in sixteenth and seventeenth century. The various European sources confirm it that these sources mention that the exports of iron were mainly from the west coast of India to the Red sea at Persian Gulf. Thus, it is crystal clear that Indian iron was quite popular in medieval world but the earliest available evidence of the export of iron from India to Persia is of seventeenth century A.D. Tavernier (1679) describes it in detail.

However, the wootz was a matter of curiosity for the Europeans. Therefore, they tried to understand physical structure and chemical corporation in late 6th & 7th century A.D. In Italy G.B. Della Porti and Joseph Moxon in Britain first made this kind of scientific study. Probably, Benjamin Heyne was the first European who studied the manufacturing process of steel in two Mysore villages in 1790 and study could be published in 1814 only. Later, Francis Buchanan studied the process of Madras Wootz and his detailed report came into existence in 1807.

Besides Heyne and Buchanan, Leochenault Dala Tour (1820), C.V.B. (1827) and H.W. Voysey's (1837) also studied the steel production of South India (Bennet Bronson, 1986, pp 13-39). In his article on "The making and Selling of Wootz, A Crucible -Steel of India", Bronson has described the following methods of wootz making in South India:

1. The Tamilnadu Process
2. The Mysore Process
3. The Hyderabad Process

The detailed description of Bronson indicates that wootz steel was manufactured in a large number of places within a region several thousand kilometers wide and a variety of quite distinct processes were used to make it which had little in common except the crucible (p. 47). According to Bronson the common denominator in the process of wootz manufacturing is a sealed crucible charged with iron and vegetable matter either small dried pieces of wood, or a few green leaves or both.

In his description Bronson also quotes Coomarswamy. According to Coomarswamy the crucible was vented rather than sealed, its lid having small holes pierced for the escape of gas. Some scholars like Rao (1970) and Tylecote (1976) state, it is not necessary to keep dried pieces of wood in crucible. The charred plant material mixed with the clay in the crucible walls might have provided enough carbon to change iron to steel (pp 39-40).

According to Srinivasan, Biswas and Srinivasan and Griffiths, Tamil Nadu was a major centre of crucible steel in India and its beginning in Tamil Nadu goes back before the Christian era (Srinivasan S. and Ranganathan, S. 1997, p. 70). A number of European travellers including Francis Buchanan and Voysey from the 17th century onwards observed the manufacture of steel in South India by a crucible process at several locales including Mysore, Malabar and Golconda. But the new researches which have been done in United States and Europe, provide a different opinion, with regard to the wootz steel. Faurbach mentions the Wilkinson's experiments and concludes that only the ingots from Cutch, on the India-Pakistan border and where the term pulad was used, produced 'Jowahar' watering. He said ingots from salem, in South India had only a slight indication of a pattern and steel was inferior, but the sample from Cutch was of excellent quality and both the "cake" and finished object exhibited a Damascus pattern (Feuerbach, Ann, 2006). In his further statement Feurbach narrates, "It seems, therefore, that wootz becomes associated with the Damascus pattern before the 1820s but the association is not made from ethnographic observations but via European replication experiments. It should also be noted that the only ethnographically produced crucible steel with a "quality" Damascus pattern was from northern India / Pakistan, which is fundamentally Central Asian, not from southern India which is associated with the term wool. Also in Northern India, the use of the word pulad (Faulad) indicates Persian connections in the process, further associating Central Asia with the presence of crucible Damascus steel swords". Probably George Pearson was the first who marked the properties and composition of a kind of steel. It was manufactured at Bombay (Mumbai) and there, they called it Wootz. In his long statement of twenty four pages in Philosophical Transactions of the Royal Society of London (Vol. 85, 1795, pp.322-346) he writes that the credit of this discovery goes to Doctor Scott of Bombay (Mumbai). In the opinion of Dr. Scott "the Wootz is so difficult, that it is a separate art from that of forging iron". In his conclusion Dr. Pearson says "Many of the proportions of Wootz, related to be those of the metallic state of iron that, but for the sake of order, I should think it superfluous to refer to any of them particularly, to support the conclusion that Wootz is at least principally iron. Wootz is proved to be iron by the obvious properties; by its filings being attracted by the magnet, by its specific gravity; by its affording nothing but sulfate of iron, hydrogen gas, and a trifling residue on solution is diluted Sulphuric acid (George Pearson, 1795, pp 336-337). Pearson also expresses his view on steel. In his view Steel is a compound of iron and carbon, the proportions of which have not been accurately determined, but may be estimated to be one of carbon and 300 of iron. I would call this state of iron from external properties, hard malleable iron, and from interior structure and composition it may be called, as in the new system, carburet of iron (ibid, p.340).

Th. Rehren & O. Papakhristu have also defined the Damascus steel. They quote P. Craddock in their definition. According them the true Damascus steel has the very low amount of slag because in its manufacturing process the slag is completely separated from the metal in the liquid state. According to them India was a major trade centre of crucible steel ingots during the pre modern India. A good number of ethnographic and archaeological reports also support it (Th. Rehren & O. Papakhrishu, 2000 p. 55). A good number of scholars like J.D. Verhoeven, A.H. Pendray and E.D. Gibson have used two terms e.g. genuine Damascus blades and pattern- welded Damascus blades. According to them genuine Damascus blades were made in Damascus, Syria from small crucible steel ingots produced in Southern India. This steel is generally termed Wootz steel. In their opinion most of the high quality Wootz Damascus blades in museums and private collections were made in 17-18th

centuries and the macrostructure, microstructure, and the chemistry of these blades have been characterized.

Thus it can be inferred without any hesitation that Damascus steel takes its name from the where medieval Europeans first encountered it. The best Damascus blades were made in Persia from Indian steel which was called Wootz. Perttula defines the best Damascus blades in which the carbon content is of about 1.5%. They were famous for their high quality and distinct surface patterns which resulted from small cementite particles arranged in parallel layers.

Recently, some scholars have done remarkable work on reproducing this ancient steel and they have reproduced it in a modern foundry. Among them Verhoeven, Faraday, Juha Perttula and Feuerbach stands the foremost. In view of Verhoeven, the original Wootz process a hypereutectoid carbon level was achieved by melting a mixture of iron sponge and wood for carbonization in small closed crucibles. But historically Faraday was the first when James Stodart in 1818 approached Michael Faraday with one of Banks Cakes to "ascertain whether any other elements were present in the wootz than iron and carbon. Faraday studied and analyzed the Indian steel or Wootz and he expressed his opinion that swords and sabos made of the so called wootz steel from India may be the best known crucible steel products, but the history and influence of crucible steel is much more subtle and wide reaching. Feuerbach has also studied wootz steel in detail he writes, "Perhaps today crucible Damascus steel is being studied and produced more than any time since its production in traditional societies". In his further discussions, he expresses his views that by combining the information from history, archaeology and anthropology that crucible steel continues to help us understand not only the people and technology of the past, but also the behaviour of materials today. It appears that crucible Damascus, steel will keep inspiring people in future also (Feuerbach Ann, 2007).

	C	Si	Mn	S	P	Cr	Mo	V	Al	Cu	Ni
Old (Average of 7 swords)	1.51	0.05	0.02	0.01	0.11	0.0	0.00	0.01	0.00	0.10	0.03

Juha Perttula has studied the compositions of steel materials used in the ancient blades. According to Perttula the preliminary tests showed that good damask could be achieved by melting scrap. The chemical composition of wootz Damascus steels are as follows which have been analyzed by Perttula (2001, p. 60): In view of Perttula, the addition of about 0.5 % Cr is essential to produce the Damascus steel because Cr also prevents graphitization.

In a joint article on The Continuing Study of Damascus steel: Bars from the Alwar Armory, Verhoeven, Pendary and Dauksch write, "In searching how to make blades that matched museum—quality Damascus blades, the authors surveyed the literature on the composition of Damascus steel blades and developed the following average composition C-1.60, Mn- 0.107, S-O.02, Si -0.043, Ni-0.013 cu-0.044 and trace Cr. (These values are in weight percent).

Thus, according to Porta it can be summarized that the old bladesmiths of Damascus utilized some sort of a rim heat treatment to allow forging of the high-phosphorous hot-short wootz ingots (Verhoeven, Pendary and Dauksch, 2007). According to Verhoeven, Pendary and Dauksch, in the early 1980s one of the authors purchased two bars of steel from R. Charlton of Damascus USA that were imported from the Alwar Armory in Rajasthan. Later, Prof. G. N. Pant examined these bars and reported to them that around two dozen such bars were at the Alwar Armory and they carried a special identification marking. There is ample evidence which provide information of iron marking at Alwar. There are reports which inform that in 1873 about 30 pre-industrial furnaces were in working condition at Alwar. Prof. Pant verified the two bars on the basis of marking and he estimated that their age must be at around 300 years old. According to him these bars had been forged from Indian wootz cakes in Persia and then sent back to India (Ibid).

Several experiments have been done by a good number of scholars during the last thirty to forty years. In their opinion "The wootz steel ingots from which the blades were made were extremely hot short due to the high phosphorus content. Successful forging requires either a rim heat treatment of the ingot or reduction of phosphorus to levels on the order of 0.03-0.04 % or less. Bronson has published the elemental composition of samples of traditionally made Indian steel and Damascus steels which are as follows:

Elemental Composition of Samples of Traditionally made Indian Steel

Steel	Origin	C	Si	S	P	MN	As
Wootz	India	1.642	0.045	0.181	ND	ND	0.037
Wootz	Mysore	0.45	0.14	0.01	0.24	-	ND
Wootz	Mysore	0.963	0.127	0.02	0.007	0.097	ND
Kheri	Jabalpur	1.214	0.095	0.002	0.140	0.296	ND

Elemental Composition of Samples of Damascus

Object	Type of Steel	C	Si	S	P	Mn
Dagger	Oriental Damascus	1.677	0.015	0.007	0.086	0.056
Dagger	Oriental Damascus	1.575	0.011	0.018	0.104	0.030
Sword	Oriental Damascus	1.874	0.049	0.013	0.127	0.005
Sword	Oriental Damascus	0.596	0.119	0.032	0.252	0.159
Sword	Oriental Damascus	1.342	0.062	0.008	0.108	0.019
Sword	Oriental Damascus	1.726	0.062	0.020	0.172	0.028
Sword	Oriental Damascus	1.62	0.027	0.007	0.087	Trace
Sword	Oriental Damascus	1.42	0.11	0.038	0.035	0.13

The above mentioned elemental composition is based on the analysis of Commarswamy, Hadfield, Henry, Percy, Sambhasiva Iyer, Zschokke and Panseri. (Bronson, 1986 pp. 33). It is clear from the above two tables that wootz samples seem rather lower in phosphorus than the swords but the similarity is otherwise clear.

Now the question arises what was the process of steel making because there are no authentic records of the Indian steel industry or the technology is used prior to the 18th century. On the basis of the available records of British engineers and investigators the following methodology can be determined.

Probably the medieval Indians had been using a small shaft smelting furnace, usually with a circular cross-section with air being blown from two bellows from the two sides of the furnace. The shaft furnace 1.5 to 2 meters high above the ground, was filled with alternate charges of iron ore properly sized and charcoal prepared from selected hardwood. At the end of smelting operation, a lump consisting mostly of reduced iron seliceous and gangue material containing some charcoal was obtained. The lump was cut into pieces by an axe while in red hot condition and the pieces were then repeatedly hammered to squeeze out the gangue and to shape it into the form of a rod or a bar-for refining and forging it later into useful articles (Banerjee, S. 1997, 85). Lowe, Merk and Thomas have studied the characterization of the Wootz steel and they have come into the conclusion that the Indian wootz white cast iron ignot was melted in a closed bowlshaped crucible at about 1200°C. The production of wootz is a batch process (as are most special steels). The crucible were not pre-fired. They used once to melt the metal, then cooled and broken to retrieve the ignot. The charcoal fire in the furnace died down and the crucibles were removed to cool slowly to produce the characteristic coarse crystalline texture of the wootz, ingot and of Damascus steel. Thermal properties controlled by high porosity and by orientation of the rice husks during fabrication favour slow cooling and controlling crystallization. The crucible vessel is refractory and insulating: the ceramic was designed for high performance in a highly specified metallurgical industry (Vandiver, Druzik and Wheeler, 1990, 627).

The reference of Iswal in district, Udaipur of Rajasthan is quite noteworthy to understand the process of smelting of iron ore. There is a large mound which has been spread in an area of 75 hectare. The maximum height of the mound from the existing surface is more than 15 meter. Huge heaps of slag can be seen on the surface of the mound which easily determines that it would have been a major centre of iron production during the early historic and medieval period of history. The C14 dates confirm that Iswal was an industrial centre of Iron. Besides the smelting and forging activities, Iswal provides the evidence of industrial colony also which makes it unique. During the course of excavation, the excavators exposed a broken furnace which belongs to 10th century A.D. It was pear shaped and it was sealed by a well plastered and rammed layer on the top and base. The height of the surviving lateral was 75 cm from the outer surface and 65 cm from the inner surface. The base of the furnace measured 83 cm in width and was 12 cm thick. During the course of excavations a cluster of broken retorts was encountered. A single piece of broken retort of about 40cm was also recovered during the course of excavation. A good number of implements have also been recovered from the site in the course of excavations. An intact iron rod which is 50cm in measurement, also recovered from the excavation.

These bits of evidence suggest that Iswal was major centre of iron production but the purpose of large production of iron is still unknown. All these evidence suggest that India was an epicenter of iron production including steel. The reasons why the Indian steel manufacturing withered during the 18th and 19th century are unknown. Probably iron production was under the guilds of traders and craftmen like other trades & crafts and it was never owned be the state in any time. The craftmen managed the all kind of raw and accessory material which was required for the non agricultural activities of Bhil Community. Out of them few has developed the skill of charcoal manufacturing for the metallurgical purpose. But the traders and craftmen of 18th and 19th century could not face the European traders because of political disintegration and social anarchy.

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