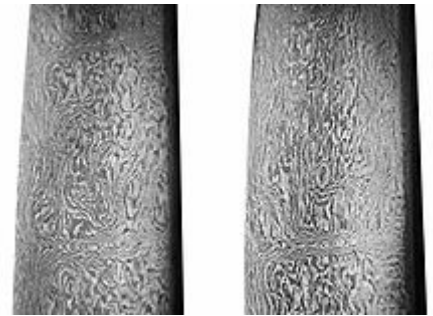


Wootz steel

Wootz steel is a crucible steel characterized by a pattern of bands, which are formed by sheets of microcarbides within a tempered martensite or pearlite matrix in higher carbon steel, or by ferrite and pearlite banding in lower carbon steels. It is the pioneering steel alloy matrix developed in Southern India in the 6th century BC and exported globally. It was also known in the ancient world by many different names including Wootz, Ukku, Hindvi Steel, Hinduwani Steel, Flint Steel and *Seric Iron*.



Picture shows 18th-century Persian-forged sword was first manufactured in the southern part of India, in Tamil nadu, on or before 11th century also later manufactured in Damascus. Crucible steels, such as wootz steel and Damascus steel, exhibit unique banding patterns because of the intermixed ferrite and cementite alloys in the steel

Contents

History

Development of modern metallurgy

Characteristics

Reproduction research

See also

References

Further reading

External links

History

Wootz steel originated in India.^{[1][2]} There are several ancient Tamil, Telugu, Greek, Chinese and Roman literary references to high carbon Indian steel since the time of Alexander's India campaign The crucible steel production process started in the 6th century BC, at production sites of Kodumanal in Tamil Nadu, Golconda in Telangana, Karnataka and Sri Lanka and exported globally; the Tamils of the Chera Dynasty producing what was termed *the finest steel in the world*, i.e. Seric Iron to the Romans, Egyptians, Chinese and Arabs by 500 BC.^{[3][4][5]} The steel was exported as cakes of steely iron that came to be known as "Wootz".^[6] Wootz steel in India had high amount of carbon in it.

The Tamilakam method was to heat black magnetite ore in the presence of carbon in a sealed clay crucible inside a charcoal furnace. An alternative was to smelt the ore first to give wrought iron, then heated and hammered to be rid of slag. The carbon source was bamboo and leaves from plants such as Avārai.^{[6][7]} The Chinese and locals in Sri Lanka adopted the production methods of creating wootz steel from the Chera Tamils by the 5th century BC.^{[8][9]} In Sri Lanka, this early steel-making method employed a unique wind furnace, driven by the monsoon winds. Production sites from antiquity have emerged, in places such as Anuradhapura, Tissamaharama and Samanalawewa, as well as imported artifacts of ancient iron and steel from Kodumanal. A 200 BC Tamil trade guild in Tissamaharama, in the South East of Sri Lanka, brought with them some of the oldest iron and steel artifacts and production processes to the island from the classical period.^{[10][11][12][13]} The Arabs introduced the South Indian/Sri Lankan wootz steel to Damascus, where an industry developed for making weapons of this steel. The 12th century Arab traveler Edrisi mentioned the "Hinduwani" or Indian steel as the best in the world.^[1]

Another sign of its reputation is seen in a Persian phrase – to give an "Indian answer", meaning "a cut with an Indian sword".^[9] Wootz steel was widely exported and traded throughout ancient Europe and the Arab world, and became particularly famous in the Middle East.^[9]

Development of modern metallurgy

From the 17th century onwards, several European travelers observed the steel manufacturing in South India, at Mysore, Malabar and Golconda. The word "wootz" appears to have originated as a mistranscription of *wook*, an anglicised version of *ukku*, the word for steel in the Kannada^{[14][15]} and Telugu languages. According to one theory, the word *ukku* is based on the meaning "melt, dissolve"; other Dravidian languages have similar-sounding words for steel. The Tamil language root word for the alloy is *urukku*.^[16] Another theory says that the word is a variation of *uchcha* or *ucha* ("superior"). When Benjamin Heyne inspected the Indian steel in Ceded Districts and other Kannada-speaking areas, he was informed that the steel was *ucha kabbina* ("superior iron"), also known as *ukku tundu* in Mysore.^{[17][18]}

Legends of wootz steel and Damascus swords aroused the curiosity of the European scientific community from the 17th to the 19th century. The use of high-carbon alloys was not known in Europe previously and thus the research into wootz steel played an important role in the development of modern English, French and Russian metallurgy.^[19]

In 1790, samples of wootz steel were received by Sir Joseph Banks, president of the British Royal Society, sent by Helenus Scott. These samples were subjected to scientific examination and analysis by several experts.^{[20][21][22]}

Specimens of daggers and other weapons were sent by the Rajahs of India to the Great Exhibition in London in 1851 and 1862 International Exhibition. Though the arms of the swords were beautifully decorated and jeweled, they were most highly prized for the quality of their steel. The swords of the Sikhs were said to bear bending and crumpling, and yet be fine and sharp.^[9]

Characteristics

Wootz is characterized by a pattern caused by bands of clustered Fe₃C particles made of microsegregation of low levels of carbide-forming elements.^[23] The presence of cementite nanowires, and carbon nanotubes has been identified by Peter Paufler of TU Dresden in the microstructure of wootz steel.^[24] There is a possibility of an abundance of ultrahard metallic carbides in the steel matrix precipitating out in bands. Wootz swords, especially Damascus blades, were renowned for their sharpness and toughness.

Steel manufactured in Kutch particularly enjoyed a widespread reputation, similar to those manufactured at Glasgow and Sheffield.^[9]

The techniques for its making died out around 1700. According to Sir Richard Burton,^[7] the British prohibited the trade in 1866:

About a pound weight of malleable iron, made from magnetic ore, is placed, minutely broken and moistened, in a crucible of refractory clay, together with finely chopped pieces of wood Cassia auriculata. It is packed without flux. The open pots are then covered with the green leaves of the Asclepias gigantea or the Convolvulus lanifolius, and the tops are coated over with wet clay, which is sun-dried to hardness. Charcoal will not do as a substitute for the green twigs. Some two dozen of these cupels or crucibles are disposed archways at the bottom of a furnace, whose blast is managed with bellows of bullock's hide. The fuel is composed mostly of charcoal and of sun-dried brattis or cow-chips. After two or three hours' smelting the cooled crucibles are broken up, when the regulus appears in the shape and size of half an egg. According to Tavernier, the best buttons from about Golconda were as large as a halfpenny roll, and sufficed to make two sword-blades. These "cops" are converted into bars by exposure for several hours to a charcoal fire not hot enough to melt them. They are then turned over before the blast, and thus the too highly carburised steel is oxidised.

According to Professor Oldham, "Wootz" is also worked in the Damudah Valley, at Birbhum, Dyucha, Narayanpur, Damrah, and Goanpiir. In 1852 some thirty furnaces at Dyucha reduced the ore to kachhd or pig-iron, small blooms from Catalan forges; as many more converted it to steel, prepared in furnaces of different kind. The work was done by different castes; the Muslims laboured at the rude metal, the Hindu preferred the refining work. I have read that anciently a large quantity of Wootz found its way westward via Peshawar.

When last visiting (April 19, 1876) the Mahabaleshwar Hills near Bombay, I had the pleasure to meet Mr. Joyner, C.E., and with his assistance made personal inquiries into the process. The whole of the Sayhddri range (Western Ghats), and especially the great-Might-of-Shiva mountains, had for many ages supplied Persia with the best steel. Our

Government, since 1866, forbade the industry, as it threatened the highlands with disforestation. The ore was worked by the Hill-tribes, of whom the principal are the Dhdnwars, Dravidians now speaking Hindustani. Only the brickwork of their many raised furnaces remained. For fuel they preferred the Jumbul-wood, and the Anjan or iron-wood. They packed the iron and fourteen pounds of charcoal in layers and, after two hours of bellows-working, the metal flowed into the forms. The Kurs' (bloom), five inches in diameter by two and a half deep, was then beaten into tiles or plates. The matrix resembled the Brazilian, a poor yellow-brown limonite striping the mud-coloured clay; and actual testing disproved the common idea that the "watering" of the surface is found in the metal. The Jauha ("jewel" or ribboning) of the so-called Damascus blade was produced artificially, mostly by drawing out the steel into thin ribbons which were piled and welded by the hammer. Oral tradition in India maintains that a small piece of either white or black hematite (or old wootz) had to be included in each melt, and that a minimum of these elements must be present in the steel for the proper segregation of the micro carbides to take place.

Reproduction research

Russian metallurgist Pavel Petrovich Anosov (see Bulat steel) was able to reproduce ancient Wootz steel with almost all its properties and the steel he created was very similar to traditional Wootz. He documented four different methods of producing Wootz steel that exhibited traditional patterns. He died before he could fully document and publish his research. Oleg Sherby and Jeff Wadsworth and Lawrence Livermore National Laboratory have all done research, attempting to create steels with characteristics similar to Wootz, but without success. J.D Verhoeven and Alfred Pendray reconstructed methods of production, proved the role of impurities of ore in the pattern creation, and reproduced Wootz steel with patterns microscopically and visually identical to one of the ancient blade patterns. Reibold et al's analyses spoke of the presence of carbon nanotubes enclosing nanowires of cementite, with the trace elements/impurities of vanadium, molybdenum, chromium etc contributing to their creation, in cycles of heating/cooling/forging. This resulted in a hard high carbon steel that remained malleable^[25]

There are other smiths who are now consistently producing Wootz steel blades identical to the old patterns.^[26]

Wootz was made over nearly a 2000-year period (the oldest sword samples date to around 200 AD) and the methods of production of ingots, the ingredients, and the methods of forging varied from one area to the next. Some Wootz blades displayed a pattern, while some did not. Heat treating was quite different from forging, and there were many different patterns which were created by the various smiths who spanned from China to Scandinavia.

Not all of the secrets of Wootz have been discovered, but it has essentially been recreated by Anosov, Pendray and many smiths in the 20th century. Nonetheless, research continues.

See also

- Damascus steel
- Iron pillar of Delhi
- Pattern welding
- Ferrous metallurgy

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