Metallographical studies of a steel chisel found at Mahurjhari, Vidarbha, Maharashtra

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Metallographical studies of a steel chisel excavated from the early Iron Age megalithic site at Mahurjhari, Vidarbha, Maharashtra were carried out. The analysis shows clear evidence of technological advance in the form of hardening and quenching followed by tempering treatment in addition to the knowledge of steeling as early as 900 BC.

Keywords: Iron processing, megalithic site, steel chisel, tempered martensite.

THE antiquity of indigenous procurement, smelting, further processing and usage of iron in India is still not clear and debatable. It is difficult to tell in which part of India it really got introduced. The early evidence of indigenous iron production probably goes back at least to the middle of the second millennium BC, evidenced from several early Iron Age sites spread across the country[1]. However, by 12th–13th century BC iron was well known and was used extensively in remote parts of the country in various way, starting from weaponry, agricultural and carpentry tools to household objects[2–5]. This technological advancement is often seen as a catalyst in the emergence of the second urbanization in India, the first being the Indus Valley Civilization. To understand the process of the second urbanization, technological achievements in iron processing must be studied. For instance, carburization of iron which played a significant role in the manufacturing of agricultural equipment and helped in the settlement of the people has not been critically evaluated in the literature. There is need for detailed metallurgical studies of ferrous objects found during various excavations[6]. Recently, we studied wrought iron samples from Mahurjhari, Naikund and Bhagimohari in the Vidarbha region of Maharashtra[7].

In this communication, we present results of metallographic studies on a steel chisel found during excavations at Mahurjhari. The Vidarbha region lies between 19°26′N and 21°47′N, and 75°56′E and 79°23′E in the northeastern part of Maharashtra. The early Iron Age megalithic culture in this region is spread over nine districts comprising Buldana, Akola, Amaravati, Yeotmal, Wardha, Nagpur, Bhandara, Chandrapur and Gadchiroli. Out of more than hundred burial sites and seven habitational sites reported from Maharashtra, except for five sites, all the rest are from Vidarbha. Again the megaliths in Vidarbha are concentrated in the districts of Nagpur, Bhandara, Chandrapur and Gadchiroli. The megalithic site of Mahurjhari is one of the richest Iron-Age burial sites excavated in India, where thousands of iron implements have been found. The people ceremonially buried their dead with goods like iron implements used for various purposes, starting from household objects and agricultural implements to offensive and defensive weapons, copper and gold ornaments, earthen pots, horse and horse ornaments and several stone objects, especially semiprecious stone beads, etc.[2]. The evidence of a iron smelting furnace at Naikund[8–12] and agricultural economy at Naikund and Bhagimohari[13,14] indicate their other economic aspects. The analysis of iron implements from the megalithic site of Mahurjhari has been encouraging, and further systematic analysis of several implement categories may give a clear picture of emerging technology around the beginning of the first millennium BC in this region.

A steel chisel obtained during excavations at Mahurjhari was cut and a sample was prepared for metallographic studies. Projectina Microscope (Swiss-make) and Nital (etching reagent) were used in the investigations.

Figure 1 shows the entire cut section of the Mahurjhari sample. Formation of flow lines on the surface of chisel implies that it was forged during fabrication. Figure 2 shows the unetched structure displaying slag and oxide particles. Figure 3 *a* and *b* shows a part of Figure 2 at higher magnification.

The light grey phase could be FeO or MnO. Darker phase could be a slag – mainly SiO_2; oxide particles are also visible.

The presence of slag in all the photomicrographs can be assigned to solid state reduction or bloomery process. Figure 4 shows the structure of core of the Mahurjhari sample.

Ferrite network on colonies containing pearlite is observed. In addition, the structure exhibits Widmanstatten pattern. Presence of ferrite and pearlite indicates the steeling attempt and the Widmanstatten structure reveals non-equilibrium processing conditions. A part of Figure 4

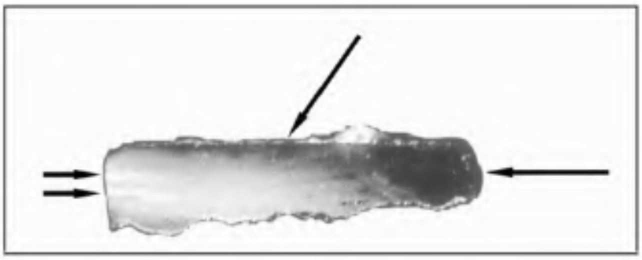

Figure 1. Photomicrograph of the iron sample from Mahurjhari. Long arrow shows darker etching tip and short arrow depicts the flow lines, × 4.75.

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at higher magnification is depicted in Figure 5. A layer of dense pearlite is observed around the ferrite network. This reveals that dense pearlite is present around the slag stringer. A part of Figure 5 *b* at higher magnification is shown in Figure 6. It shows dense pearlite. Darker etching area of Figure 6 *a* is shown in Figure 6 *b*.

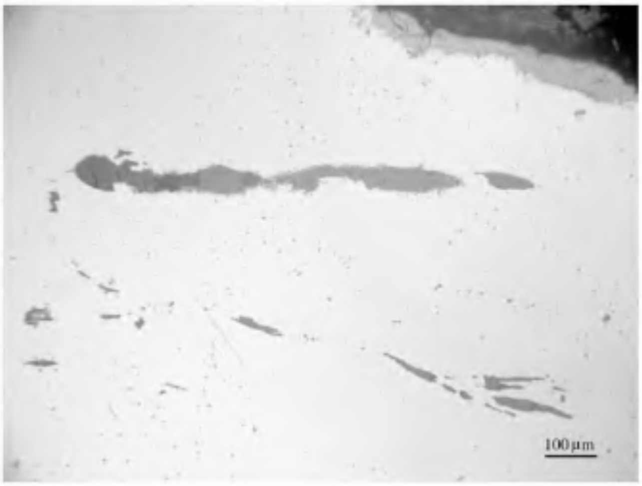

Figure 2. Unetched structure showing slag and oxide particles. (Top right) Surface with oxide layer, ×100.

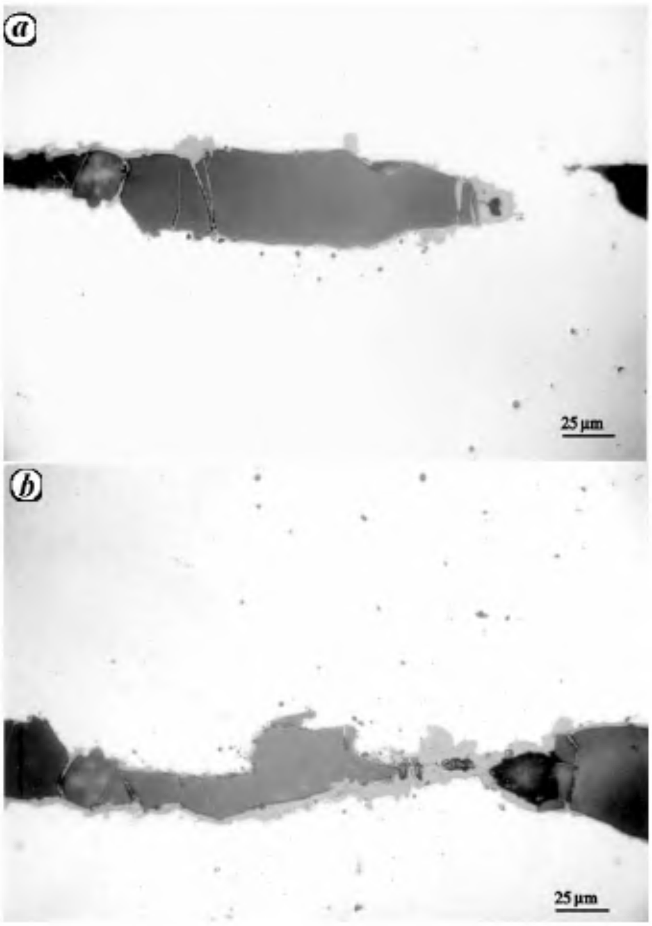

Figure 3 ***a*****,** ***b*****.** A portion of Figure 2 at × 400.

Martensite is a supersatured solid solution of carbon entrapped in body-centred tetragonal structure. During tempering, the carbon gets precipitated as carbide and the iron becomes body-centred cubic. When the carbide particles precipitate, etching response becomes more rapid in comparison with untempered martensite. Consequently tempered martensite appears darker. At the same time, the lenticular or plate shaped individual martensite needles become blunt. By observing the etching response and rather blunt shape of individual martensite needles in the microstructure shown in Figure 6 *b*, it can be concluded that the martensite is tempered. Observation of the dark carburized tip after etching of the chisel as shown in the Figure 1 supports this conclusion.

The melting point of pure iron is 1540°C. In the ancient Indian furnaces that were used to extract iron from its ore, it was not possible to attain such higher temperatures required for melting of iron. Therefore, the reduction of iron was performed in the solid state at a temperature of about 1100–1200°C in bloomery furnace. The end product of reduction of iron ore was an iron bloom which was utilized to fabricate commercial objects. This technique is known as solid state reduction process or bloomery process. Absence of as cast structure in photomicrographs confirms that the chisel under study was made by solid state reduction. Further, it could be inferred that the chisel was made from solid iron bloom in the stages. Flow lines on the surface of the chisel reveal that it was forged probably in charcoal fire. During forging, the slag separated out and the surface of the chisel was progressively carburized to make it steel at least at the edge. The solid state carburization is also known as steeling – a process in which carbon gets diffused into iron at higher temperature. The depth of diffusion of carbon depends upon the temperature and time. The resulting product

Figure 4. Structure of core of the sample from Mahurjhari at × 100.

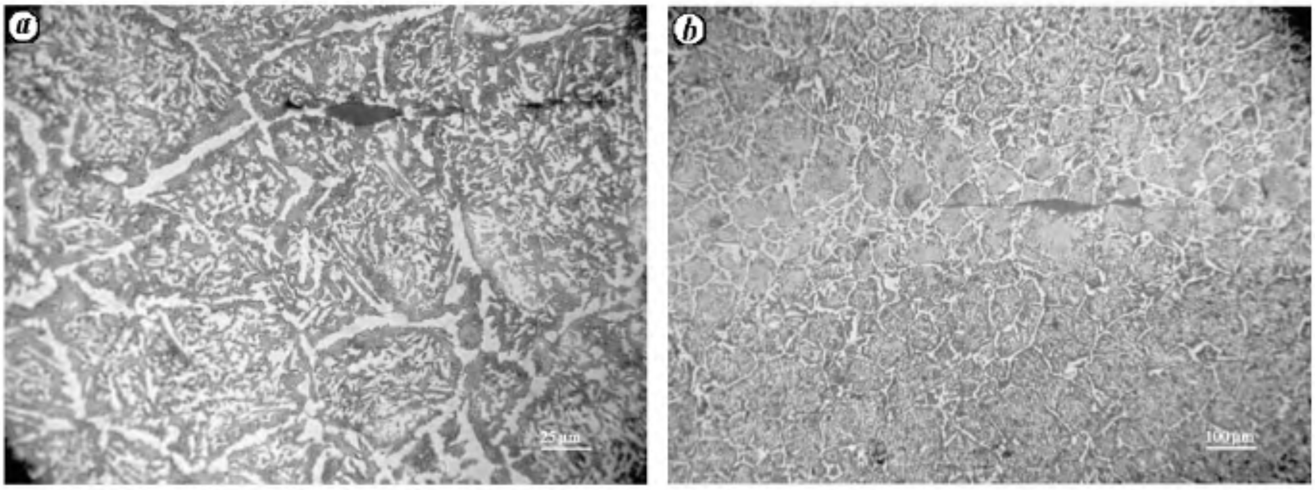

Figure 5. Part of Figure 4 at × 400 (***a***) and × 100 (***b***).

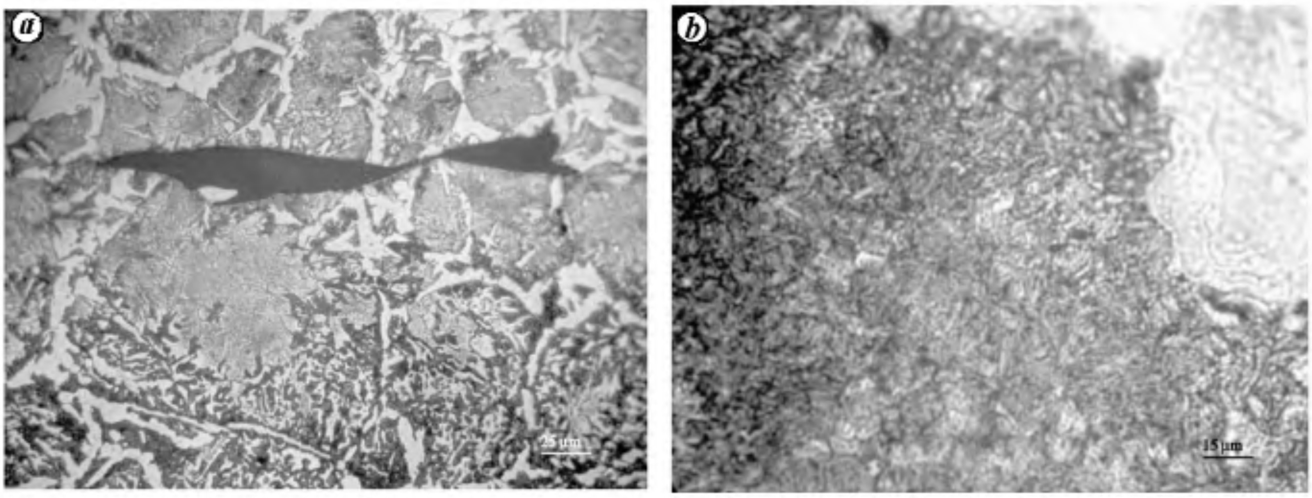

Figure 6. ***a***, Part of Figure 5 *b* at × 400. ***b***, Darker etching area from Figure 6 *a* at × 650 showing tempered martensite and oxidized surface (top right) corner.

containing high carbon can be hardened and quenched. The presence of ferrite network on pearlite in the microstructure of the chisel can be attributed to the technique of intentional carburization or steeling of wrought iron bloom in order to make it steel. Widmanstatten pattern observed from microstructure implies that the chisel must have undergone non-equilibrium cooling at some stage during its manufacturing sequence. After deliberate carburization, the chisel was hardened and quenched to impart hardness at the edge. Subsequently it was reheated, i.e. tempered at lower temperature to avoid cracking and distortion during its use. Observation of tempered martensite in the microstructure of the chisel confirms this, i.e. heat treatment of the chisel consisting of hardening, quenching and tempering at lower temperature.

The metallograhic studies show that the steel chisel obtained from the Mahurjhari site was made by solid state reduction or bloomery process. The iron bloom obtained was then forged in charcoal fire and deliberately carburized to make it steel. Finally the chisel was hardened, quenched to impart hardness and subsequently tempered at lower temperature to eliminate chances of cracking and distortion during its use. To sum up, these studies indicate that not only deliberate carburization or steeling of wrought iron, but also the sequence of heat treatments – hardening, quenching and tempering were known around 900 BC in the Mahurjhari region.

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Influence of levels of genetic diversity on fruit quality in teak (*Tectona grandis* L.f.)

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The study on the influence of genetic diversity on the fruit emptiness and seed germination (as a measure of fruit quality) of teak populations was carried out. The populations comprised three unimproved plantations, three seed-production areas and a clonal seed orchard within Karnataka. Significant variation between the populations was observed for fruit emptiness, seed germination and Jaccard's dissimilarity index of the parent population. Genetic dissimilarity of populations was positively correlated to fruit emptiness and negatively correlated to seed germination. It is inferred that higher genetic dissimilarity of individuals within the population results in higher flower asynchrony and close-related mating, thereby leading to higher inbreeding depression manifested in the form of higher emptiness and low germination percentage.

Keywords: Flower asynchrony, fruit emptiness, genetic diversity, seed germination, teak.

TEAK (*Tectona grandis* L., family Lamiaceae) has been recognized as the most valuable and premium wood in the world's timber trade. Presently, it is grown in plantations across 36 tropical countries of Asia, Africa and Latin America[1]. Considering the net area of teak plantations in 1995, about 94% lay in tropical Asia, with India (44%) and Indonesia (31%) contributing the bulk of the resource[2]. In India, teak ranks second only to *Eucalyptus* in terms of plantation area (8.67%)[3], with an annual plantation rate of around 50,000 ha. Consequently, there is a great demand for quality planting materials across the country.

The most ideal source of quality seeds for the purpose of raising plantations are clonal seed orchards (CSOs). However, the seed yield among teak CSOs has been low in India[4] and other South Asian countries[5]. As a result, much of the seed demand is met with from seed production areas (SPAs) and sometimes unimproved plantations

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