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ARCHAEOMETALLURGICAL STUDIES IN INDIAN SUBCONTINENT: A SURVEY ON METALLOGRAPHY OF IRON OBJECTS

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Archaeometallurgy is a rapidly growing discipline worldwide. In India, some researches were carried in this branch of science. In brief, this topic includes the published works by the various authors on Indian subcontinent. Specific studies revealed the features of Iron Pillar of Delhi. Others include the specimens from 1200 B.C.

INTRODUCTION

Archaeometallurgy is a rapidly growing discipline worldwide. In Europe and USA, this branch has been thoroughly developed by the metallurgists or by both archaeologists and metallurgists. This multidisciplined branch is developing fast with the application of metallography, electron microscopy, computers and other most modern instrumentations to analyse the technology of metal crafts of the ancient world. In this field, we should mention the researches of J. Piaskowski, V. C. Piggot, R. Maddin, T. S. Wheeler, R. Knox, R. F. Tylecote, P. T. Craddock, U. M. Franklin, H. Lechtman, W. T. Chase etc. A large number of papers have been published by them.

First systematic studies on iron age began in India by Banerjee.[1] He himself excavated various archaeological sites pertaining to iron-using culture. V. S. Wakankar took extensive excavations in Madhya Pradesh and discovered series of sites where iron was found in cultural assemblage. Chakrabarti excavated few sites and extensively explored eastern, western and northern India and published widely about iron. His unique excavation in Bahiri, West Bengal[2] threw new light on iron age of this region. Sahi excavated a few interesting sites in Uttar Pradesh and published some valuable papers[3,4] on iron. Nagaraja Rao excavated and published much about South Indian iron-using culture. Gogte extensively studied the megalithic technology of iron smelting at Naikund. Agrawal's contribution must be mentioned here for his radiocarbon chronology of the archaeological sites. Moreover, he contributed in the field of archaeometallurgy of copper-bronze.

In the Indian sub-continent only a limited number of papers have been published so far partaining to the metallography of ancient iron objects. Metallography is one of the most important branch of metallurgy and is concerned chiefly with the internal structure of the solid formed during solidification and subsequent mechanical and thermal treatment. In the beginning of this century, the main tool was an optical microscope with a low magnification. But now-a-days scanning and transmission electron microscopes have increased their field by thousands of times. Due to the paucity of work in our country it is still uncertain to get the correct picture of the metallurgical development of this.

To know in depth is, however, difficult since the majority of metal specimens for studies are completely corroded. Though Knox[5] had developed a unique method to determine the relic carbide structure in corroded metals, yet this method could not be fully satisfied with Indian specimens. These are, however, still under the field of research. Another problem is with the museum specimens. Here practically the metals with less-corrosion are considered as an important art object where authorities seldom permit to part with even a thin slice of metal from these objects.

Research on Indian Specimens

The famous iron pillar of Delhi has been much appreciated since a long time by the archaeologists and scientists all over the world. Both the metallurgists as well as the geologists wrote much about its technological features. Hadfield,[6] the giant steel-maker of the beginning of the present century, studied about the chemical phenomena of its constituents. His pioneering work in this discipline not only concentrated with the iron pillar alone, but also extended towards a few iron objects from Taxila. The implements of *c.* 100 A.D. like two swords and one adze showed the spherodized pearlitic structure with preserved traces of cementite grains.[7] These are the same as the modern high carbon steel, some other specimens of low or medium carbon steel were also reported by him. Graves[8] also did some work in this field with specimens of Indian sub-continent.

Friend and Thorneycroft[9] examined the iron from Konarak. They had analysed the chemical composition of the metal; took hardness and got the photomicrograph with a magnification of 50. The etchant used was a solution of picric acid and alcohol. The constituents were ferrite and pearlite. The method of manufacture was by welding together small blooms and apparently, decarburisation took place during the operation of welding.

In the seventh decade of this century, a considerable interest on iron pillar was taken again by the scientists of National Metallurgical Laboratory, Jamshedpur; Ghosh[10] did a thorough study on its chemical and metallographic characteristics. His series of photomicrographs reveal that the iron of the pillar mostly consists of medium to course polyhedral grains of ferrite. Slag particles were found with a pattern of irregular distribution. Small amounts of pearlite were noticed at grain boundaries and its concentration was found to be slightly higher at the interior. The oxide films and deformed structure clearly indicate that it was entirely a forge-welded product. The micrographs showed a series of such arreas at different regions. Ghosh had also analysed few pieces of megalithic iron specimens of Sonur,[11] details of which are not known.

Here we shall also mention the arechaeometallurgical studies on the corrosion resistance of the iron pillar and the present time adivasi iron by the metallurgists, Lahiri, Banerjee and Nijhawan[12] of the same organisation. They found the wide structural variation at places from Widmanstätten structure, normalised, annealed, highly distorted slipbands in ferrite, nitride, carbide, slag masses, stringers, envelops—around metal grains and forged welded zones. The pillar was manufactured by forge welding and the entire pillar was rounded off with forge hammering, cold working and distortion. According to the authors, the corrosion resistance was due to the mode of manufacture.

Athavale[13] studied the iron specimens from Prakash, Maharastra. Amongst 31 iron objects 7 specimens were selected for chemical analysis. From these two shaft-hole axes (earlier of them was of *c.* 100 B.C. level) were metallographically analysed. Both the metallic core and the outer oxide portion were studied. Equiaxed ferrite with a small amount of pearlite structure was observed.

Prakash and Singh[14] studied the iron objects from Kausambi. The carbon content of the steel was nearly eutectoid and the pearlite structure was found in those iron objects. Bhardwaj[15] analysed the excavated iron specimens of Rajghat, Varanasi, U.P. Amongst the six pieces of iron objects of the site he got the metallograph of arrow-head, nails and a rod. His photomicrograph were with a magnification of 100-200. Nital was used as etchant. Mostly, the metals were of equiaxed ferrite with slag inclusions with no clear evidence of pearlite. In one specimen small amount of cementite was noticed. He assumed that probably the process of carburizations was known to the blacksmiths of Rajghat.

Hegde[16] studied the details of iron metallurgy at Dhatwa, Gujarat. Detailed work was carried out by this author on ores, furnaces and the roasted metal itself. Metallographic studies were carried on a hoe. With its laminated structure, variable hardness, carburised structure, the author proved the mature, painstaking and laborious forging technique of the Dhatwa smiths.

Agrawal *et al.*[17] did some valuable work on the iron implements from the megalithic site Tadakanahalli. This 1000 B.C. site was excavated by M. S. Nagaraja Rao. An axe and two implements like the implements used by the present-day cobblers were examined by Agrawal *et al.* Knox's technique was used by the authors. They have claimed the presence of ferrite and pearlite, some relic carbide structure along with bainite and martensite. They have used the magnification from 126 to 1200, but from the published photomicrograph nothing can be ascertained about the presence of martensite or bainite.

Ghosh and Chattopadhyay[18] studied on early steel implement from Barudih, Bihar. They have clearly shown the presence of pearlite, from coarse granular to lameller, at places in equiaxed ferrite matrix. The structures at 300 and 1000 magnification clearely indicate that it was a normalized structure. That is, the implement was thoroughly forged and cooled slowly in air. The implement is made of a low carbon steel, an intriguing fact given its early iron age date. This is a singular artifact in that assemblage which otherwise has a neolithic character. Four radiocarbon dates had been obtained from that site, the earliest of that is 1200 $\pm$ 210 B.C. (TF 1100) and the weighted average of these date is 810 $\pm$ 55 B.C.

Chattopadhyay[19] also studied an iron razor of Ror, district Kangra, Himachal Pradesh. The site was excavated by D. K. Chakrabarty. This iron razor was micrographed with a magnification of 315, revealed structures composed of massive ferrite and in some places polyhedral ferrite grains without any carbon. Martensitic characteristics are prominent with martensite plates and intersecting 111 plane. Published micrograph contains both martensite and massive ferrite. The smiths were thoroughly conversant with the technique of rapid quenching.

Agrawal[20] has contributed a detailed report of some antiquities of Atranjikhera, U.P. His studies—both metallurgical and chemical, iron-copper, slags and local ore. The site was excavated by R. C. Gaur and his colleagues at Aligarh Muslim University. In this site iron implements have been found right from the beginning of painted grey ware of *c.* 1100 B.C. The antiquity of iron thus has been pushed back to the late 2nd millenium B.C.

Four samples of iron specimens were found with ferrite and in three samples with a little of pearlite. It appeared from these studies that the metal was wrought iron with minute surface carburisation during forging.

Prakash and Igaki[21] have published the details of iron-making techniques by Mundia and Halbi tribes of Bastar, M.P. Presence of high carbon case in the microstructure (100X) is also reported by them.

Gogte[22] has contributed a detailed report of iron and copper specimens in Mahurjhari Megaliths. Both chemical and metallographic studies of five iron objects were done. From these studies it was found that this Megalithic irons were plain medium carbon steel. Evidence of banded structure, widmanstätten structure, ferrite and pearlite structure indicate that the iron pieces werd forged at high temperature.

From these published papers it is clear that the ancient Indian technology of iron was quite advanced. Chronologically it may be seen that the technology was developed varying in degrees from place to place. Carburisation and quenching techniques were satisfactorily known to the Indian smiths.

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