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BOOK REVIEW

R. Balasubramaniam, ***Story of the Delhi Iron Pillar*** Foundation Books Pvt. Ltd., New Delhi, 2005, Pages xi+99, Bibliographical References 47, Plates 40, Figures 20.

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The review of this beautiful book could have been written a year ago, but the promised copy reached the reviewer only last month (March 2008). As the adage goes, it is better late than never. After all, it took fourteen centuries for the historical amnesia regarding the famous Mehrauli (Delhi) Iron Pillar to be overcome, when in 1828 one British Captain Archer spotted it and the inscriptions which 'nobody can read'!

The massive, nearly seven tons in weight, 23 ft. tall, tapering 16" to 11" diam., Iron Pillar in South Delhi has been an object of considerable interest to the 'historians as well as modern scientists and technologists all over the world. How could such a huge forge-welded corrosion-resistant iron structure be manufactured in Ancient India? Most recently (2007), its creation has been ranked as one of the top 50 metallurgical wonders of the world, 'fifty greatest moments in materials' by the Minerals, Metals and Materials Society.

When Professor T.R. Anantharaman, the famous metallurgist and material scientist of the Banaras Hindu University published his book: *The Rustless Wonder- A Study of the Iron Pillar at Delhi* (Vigyan Prasar, New Delhi, 1996), his erstwhile student, the author of the book under review, had already started his independent archaeometallurgical research on the pillar at the Indian Institute of Technology, Kanpur. His research conducted up to 2001 was reported in a technical book: *Delhi Iron Pillar: New Insights* (Indian Institute of Advanced Studies, Shimla and Aryan Books International, New Delhi, 2002).

In 2003, Balasubramaniam prepared a separate manuscript entitled *Story of the Delhi Iron Pillar* and kindly provided a personal copy to me. His motivation for the abridged version was the following. The hard copy book *New Insights* (2002) had been primarily designed as a research book 'meant to serve as a standard reference for the scholars'. Many people, specially the students, requested him to 'provide a simplified view of the subject discussed in the hardback edition'. Hence a separate manuscript was compiled in June 2003 with 156 references, 51 plates and 27 figures. Even these numbers were pruned and the text shortened in several places when the printed book under review came out in 2005. On the other hand, the author has introduced in the printed book, the contents of his more recent (2001-2005) research on the subject such as the astronomical significance of the iron pillar etc.

I have cited and contrasted Balasubramaniam's presentations dated 2002, 2003 and 2005 merely to indicate that the author might have faced the dilemma which I share with him. Should such a multi-disciplinary subject be treated with the fullest technical details, or semi-technically, or in a popular style, when the possible criticisms could run in opposite directions namely the presentation is 'too technical' or 'not too technical'! Be that as it may, I would restrict my comments on to his 2005 publication.

This thin book of 99 pages has 20 figures and 40 excellent plates. The book is divided into five chapters:

I. Introduction, II. History of the Iron Pillar, III. Its Structural Features, IV. Manufacturing Methodology, and lastly V. The Pillar's Resistance to Corrosion. In the 'Epilogue' the author raises the question whether the knowledge accumulated about the Delhi Iron Pillar can be used in modern technology, and offers a positive answer.

The Introduction is much too short and there is a glaring error in page 4, wherein the author states that James Prinsep published the oldest Sanskrit inscription on the pillar in 1817 in the *Journal of the Royal Asiatic Society*. If the date and the name of the journal cited are correct, then the communicator could have been H.T. Colebrooke and not James Prinsep who arrived in India as a young person in 1819 and wrote his internationally famous papers on the pillars, Asokan and Gupta Brahmi inscriptions much later, during 1834-1838.

The IInd Chapter traces the history of the Pillar from the identification of the monarch who erected the pillar, its original erection site, to the movement of the pillar to its present location. It is now reasonably established that the Delhi Iron Pillar was originally located in Vishnupādagiri, at present known as Udayagiri, fifty kilometers from Bhopal. One of the Gupta monarchs, Chandragupta II Vikramaditya (375-414 AD) erected the pillar sometime around 402 AD. Iltutmish (1210-1236 AD) shifted it in 1233 AD as a booty of war from Udayagiri to its current location in the Quwwat-ul-Islam (Might of Islam) mosque in South Delhi. Iltutmish also vandalized the nearby town of Ujjain, destroyed the idol temple of Mahakal, and took away the stone idol and the brass effigy of Vikramaditya.

Balasubramaniam has established the astronomical significances of Udayagiri (also Ujjain) which are located very close to the Tropic of Cancer (latitude 23° 39' in 400 AD). This area as well as the era are connected with the 'nine jewels' of Vikramāditya, such as the astronomers Āryabhaṭa and Varāhamihira, the encyclopaedist Amara Deva whose inscription in Bodh Gaya was discovered and described by Charles Wilkins in 1785, and the poet Kālidāsa, the author of *Raghuvaṃśa*, whose descriptions about the conquest of Bengal, the Scythian country on the Indus and South India upto the Indian ocean corroborate the descriptive inscriptions on the Delhi Iron Pillar.

As more archaeological discoveries are being made around the Bhopal-Sanchi area, we may hope to discover the metallurgical centres around the Udayagiri locality and learn more about the ancient technologies related to the Pillar.

In Chapter III, Balasubramaniam moves on to the Structural Features of the Pillar: the buried part of the pillar, details of the pillar under the ground, the relative dimensions of the Delhi Iron Pillar, of the decorative bell capital, original image atop the pillar and the box pedestal, schematic depiction of the *cakra* image that was originally on top of the Delhi Iron Pillar, and lastly, the possible fitting methodology employed to construct the capital.

Chapter IV has been devoted to Manufacturing Methodology: how did the ancient Indians extract iron, what was the composition and microstructure of the pillar, how was the pillar manufactured, whether by vertical or horizontal forge-welding, how was the pillar handled while manufacturing, use of clamps and rotating pegs, how was the surface of the pillar finished, and many other related questions.

Several analyses of the composition of the pillar have been available since R. Hadfield published the first analysis in 1912. The ancient Indian irons show variation as well as some trend in the compositions: low carbon content, very small percentages of manganese and sulphur and relatively high phosphorus content which according to several authors, including Balasubramaniam, contribute to corrosion resistance. The Iron Pillar has substantial heterogeneity and the variations in the analytical values obtained by several scholars may be noted:

Iron: 99.67 to 99.72, Carbon: 0.03-0.90, Silicon: 0.004 - 0.056, Sulphur: trace to 0.008, Manganese: almost nil and Phosphorus: 0.114 - 0.48. (all percentages).

The slags generated in the ancient Indian furnaces were essentially fayalitic slags, iron orthosilicates, and did not contain lime CaO which is superior to FeO in its efficiency for removal of phosphorus from the metal. That probably explains enrichment of phosphorus in the ancient metal. Still, it is to be investigated whether the bulk of the phosphorus entered into the metal from the ore or the charcoal ash; the composition of the latter may be crucially important, not only in terms of P, but also K, B,N etc This reviewer has noticed that the *Rasaśāstra* texts recommended the choice of specific plants for the production of charcoal ash and subsequently ferrous materials.

Electron microprobe microanalyses revealed that there is no surface enrichment of elements like Mn, Cr, Cu and Ni on the pillar which could contribute to surface alloying and corrosion resistance. The pillar is highly heterogeneous, the slag inclusions being irregularly distributed in the microstructure, not coating the individual lumps which were forge-welded. This provided good yield strength and tensile strength to the pillar. Very recently, Balasubramaniam has surmised that a cannon ball fired at the Delhi Iron Pillar in the eighteenth century (either by Nadir Shah in 1739 AD or Ghulam Quadir in 1787) failed to break the pillar.

Close observation of the deformation lines indicates that the flow of metal was due to application of force perpendicular to its surface (circular cross-section). This suggests that the lumps must have been added by sideways forging. What was practised was horizontal forge welding technology by adding metal sideways. While manufacturing, the pillar was handled by clamps and rotating pegs.

The smooth surface finish of the Delhi Iron Pillar and the Aśokān Stone Pillars has not been adequately explained. Balasubramaniam hin~s to 'a technique that is now unknown'. The present reviewer has a pet theory that an abrasive such as corundum or *kuruvinda* was used for the last stage of fine polishing. Corundum mines were known in the Rewa State during Aśoka's reign, and the material used to be exported to Rome & other Western cities.

Being internationally reputed as a materials scientist, corrosion expert and an archaeo-metallurgist, Balasubramaniam wrote his last and the best chapter in the book, entitled "The Pillar's Resistance to Corrosion".

Balasubramaniam considered two rival theories underlying corrosion resistance of the pillar, the first related to the low relative humidity of the Delhi environment and the second related to the composition of the pillar containing substantial amount of phosphorus. His research seems to indicate that the second (compositional) factor is much more important then the first.

The process of protective film formation on the Delhi Iron Pillar has been scientifically verified by studying the rust samples using X-ray diffraction, infrared spectroscopy, Raman spectroscopy and Mossbauer spectroscopy. In the successive stages of rust formation, one finds lepidocrocite (γ - FeOOH), goethite (α - FeOOH) , magnetite and then the protective but discontinuous layer of δ FeOOH. This layer gradually gets enriched in phosphorus which with moisture gets converted to phosphoric acid and then amorphous phosphate. The amorphous layer finally gets converted to the most protective yellow layer of crystalline phosphate $FePO_4$, H_3PO_4, $4H_2O$. A freshly cut surface has been found to change its colour over a period of three years to be indistinguishable from the rest of the surface, clearly indicating that 'resistance to corrosion is an inherent property of the material of the Delhi Pillar'.

The phosphate layer theory for the corrosion resistance of the pillar seems to be the dominant mechanism, but does it totally eliminate the environmental aspect, the humidity factor? The author admits that there has been significant rusting in the buried region of the pillar (soil corrosion) and also in the hollow slot at the top of the decorative bell capital (immersed corrosion on account of the collected rainwater) which could not be prevented by the presence of phosphorus in the material. The figure xvi indicates substantial amount of corrosion in the pillar during the high humidity monsoon season (July to September) in Delhi. Fortunately the Delhi atmosphere does not have high relative humidity during the rest of the year.

The author admits that ‘the mass metal effect (large mass absorbing huge amount of heat during the day and counteracting dew precipitation during the night) is a contributory factor to the resistance of the pillar to corrosion, but not the sole reason’. True, there is no single, exclusive ‘sole’ reason. There are several factors contributing to the cumulative effect. Can these separate contributions be quantified by an outstanding corrosion scientist such as Professor Balasubramaniam? Would he agree that the corrosion resistance of the Delhi Iron Pillar is at least partly due to Delhi (environment) though substantially due to Iron (composition)? There is the need for controlled experiments on the ancient irons in Konarak, Puri etc., and on the corrosivity of specially prepared phosphoric iron samples in the high humidity sea-coast areas.

The author has presented to us an excellent ‘Epilogue’ suggesting the manufacture and use of corrosion-resistant phosphoric iron in the modern world. His idea needs very careful deliberations. Phosphoric irons may fare successfully in reinforcement bar application. If his ideas are adopted, it would clearly show that our knowledge of the ancient technology can certainly help us in the modern context: ‘the best of the new is often the long forgotten past’.

The *Story of the Delhi Iron Pillar* is indeed a fascinating narrative, providing glimpses of the Indian past, present as well as the future. The students and scholars would be equally benefitted by this stimulating account. This book deserves to be purchased by all libraries, and since the cost is low, may be owned by individuals as well. I heartily congratulate the author for his excellent work and hope that he would write many more books of this calibre.