reports, figures, line drawings and photographs. This book certainly has a great research value to understand the origin, growth and spread of iron technology in India. It is also useful to the students who are interested in knowing the history of science and technology in India. Finally, one should also appreciate the Infinity Foundation for supporting and encouraging such studies.

R. Balasubramaniam, ***Marvels of Indian Iron Through the Ages***, Infinity Foundation Series, Publisher- Rupa & Co., New Delhi, India.

Reviewed by: B. Prakash, Former Professor, Department of Metallurgical Engineering, Institute of Technology, Banaras Hindu University, Varanasi. India. **Residence:** C/o Mr. Nikhilesh Kumar, 17-D/709, Vasundhara, Ghaziabad- 201012.

This book presents a glimpse of the traditional knowledge and skill of the ancient Indian metal technologists and black smiths to design and construct massive wrought iron pillars and forge welded iron cannons of various calibre as well as to manipulate the thermo mechanical working of Wootz steel to produce World famous Damascus swords and other war weapons and armours etc. from this Ultra High Carbon steel. The text is basically based on the review of the published literature and the research work done by Dr. Balasubramaniam and his group during the past three decades in the field of archaeometallurgy of iron and steel and their corrosion behaviour at the Department of Materials and Metallurgical Engineering, Indian Institute of Technology, Kanpur.

In his editorial D.P. Agrawal has rightly pointed out that the achievement of such technological skill by the ancient Indian iron and steel craftsmen are conspicuous by their absence in the Western version of global history of science and technology which suffers from Eurocentric distortion tracing back any ancient achievement to Greece.

This book is a complementary volume to the book by Prof. V Tripathi on '*History of Iron Technology*' in India presenting the archaeological evidence to prove the independent beginning of ancient Indian iron extraction process as early as 2m BC and its possible outward diffusion to the neighbouring countries.

In this book Balasubramaniam presents a critical review of the published literature on ancient Indian iron and steel and the smithy skill of the ancient black smiths which has resulted in the design and fabrication of massive iron pillars like Delhi Iron Pillar and wrought iron cannons, the discovery of the super plastic property of Wootz steel and reproduction of the World famous Damascus sword's surface structure, and their excellent weather resistance. Balasubramaniam has written this book in four major chapters to present his own studies and researches on the subject.

Balasubramaniam has devoted the first introductory chapter to explain the basic rudiments of metallurgical engineering and technology of iron and steel in a very simple language which could be easily understood by general readers of this book. In this chapter he has explained the ancient as well as modern processes of iron making and the effect of 'C' on the properties of iron i.e. the process of steeling, and the ancient classification of iron-- carbon alloys and their properties as well as the ancient knowledge regarding their mechanical behaviour. Following this he has explained various mechanical operations like hot and cold working of these alloys to fabricate various iron and steel objects. He has also explained the processes of metal joining and casting to produce beautiful bronze and brass icons by lost wax moulding process.

In this chapter while explaining the principles of iron extraction (page 2) the author has not mentioned the direct reduction of iron oxides (ore) by hot 'C' or char coal which plays a vital role during the production of iron in the short bloomery furnace where in spite of the strict process control the chemical reduction time by CO gas is only of the order of a fraction of a second.

In second chapter on pillars and beams Balasubramaniam has discussed the forging and forge welding skill of ancient Indian black smiths to produce massive iron pillars of beautiful design like Delhi Iron pillar and others at Dhar and Kodachadri as well as heavy square iron beams used in the construction of temples in Orissa.

The wrought iron pillar at Delhi constructed in 4th AD has been claimed as the 'Rustless Wonder of the World' because of its design, workmanship and its excellent corrosion resistance. Balasubramaniam has reviewed the past history regarding its antiquity and the place of its construction. He has presented new archaeological evidence in favour of its initial erection at Udiagiri near Sanchi (M.P.) as the *dhwaja stambh* of Lord Vishnu as shown in the stone carving of Vishnu cave. This shows a *cakra* on top of the bell capital of the pillar carved near the feet of Lord Vishnu. If there was any such *cakra* erected on the Delhi iron pillar it has been lost or destroyed during its shifting to the present site. The author has studied this pillar in detail and published large number of photographs to show the details of the construction and the corrosion protective layer on the pillar's surface. Following this he has described the possible manufacturing methodology used during its construction by forge welding bright red hot wrought iron blooms/refined square bars and shaping them into circular pillar by hot forging in horizontal position.

For the construction of the bell capital he has proposed this being made in several pieces and assembled together by shrink fitting on a hollow cylinder reinforced and held at the top of the pillar with the help of solid iron inserts. This plausible design, concept and construction needs confirmation using ultra sound and gama ray imagery. Based on the corrosion studies carried out by Balasubramaniam and his group on the wrought iron of ancient origin Balasubramaniam has proposed a novel theory for the corrosion resistance of this pillar due to the formation of a protective impervious layer of $FePO_4$, H_3PO_4. $4H_2O$ below the layer of iron oxides and iron hydroxide. He has attributed the bluish reflection from the surface of the column (Fig. 2.17) being due to the phosphatic coating on the surface. Based on this dual passivation film theory he has credited the ancient Indian iron producers with the capability of making wrought iron high in phosphorous (0.114 to 0.436 %) using Indian iron ore which is known tobe very low in phosphorous.

Further, the author has tried to trace the history of Dhar iron pillar constructed during 11th. AD by King Bhoj at Mandu (M.P.) . At present it is lying in three pieces near Lal Masjid at Dhar, and a fourth piece has been lost during its shifting to the present location. This 14.9 m long iron pillar has a square cross section at the bottom which gets converted into octagonal and finally into circular cross section. Balasubramaniam has quoted the construction details proposed by Prakash and suggested a similar procedure with slight modification i.e. use of tapered pins instead of circular ones to join small pieces forged separately. His study on the passivation characteristics of wrought iron used in the construction of this pillar has been found to be better than Iran iron and 0.05 % 'C'steel. This shows the superiority of iron produced in the country even during 12th AD. The rust characterization study reported by Balasubramaniam and Ramesh Kumar has indicated the existence of crystalline ferric oxide and phosphate phases and amorphous hydroxide phase. The anodic passivation study carried out by Igaki has shown the wrought iron of Indian tribal origin to have better passivation characteristics than ancient iron of many other countries and even ultra pure iron prepared in laboratory.

The author has also reviewed the available literature to establish the use of as many as 200 massive iron beams in the construction of temples in orissa ever since 6^{th} AD. The broken cross -section of some of these beams lying in open saline atmosphere by the side of the Sun temple at Konark have revealed these tobe constructed by forge welding large number of square iron rods(~25mm sq.) . Jena and his colleagues at RRL Bhubaneshwar were the first to report the presence of lead in the crevices of these rods. Bonner and Sharma have translated the Oriya text of the court account confirming the purchase of large quantity of lead at the time of manufacture of these beams in 9th AD. The rust layer of these beams has shown the presence of magnetic Goethite and Lipidocrocite.

At the end of this chapter the author has described another iron pillar erected as *dhwaja stambh* at Mookambiba temple on Kodachadri hill in South India. This pillar is supposed to have been constructed from wrought iron produced in the near by area and it is standing facing the saline wind from the sea. The author could have completed the list of ancient iron pillars found in the Subcontinent by providing a report on the trident erected at a temple at Mount Abu and the ~2m high trident as well as iron pillar at Tanginath temple near Netarhat (Bihar).

During his study of Delhi iron pillar Balasubramaniam had found some lead residue in the crevices of the bell capital (ref. pp.14, 53), and based on this finding he has suggested the use of lead based solder to join various decorative parts of the beautiful bell capital (Figs. 1.6 & 2.19 to 2.21) The XRD of this lead sample has confirmed this to be $PbCO_3$. $Pb(OH)_2$. H_2O and $PbCO_3$ and no presence of tin has been detected. (Balasubramaniam, 1999 b). It is well known that tin is an essential part of lead solder without which liquid lead does not wet the iron surface and form bond. More over, lead and tin react with the atmosphere and with the passage of time get transformed into respective chemicals loosing the bond strength. Hence, Balasubramaniam's assumption regarding the use of lead solder to join various parts of the bell capital seems to be misleading, because in that case these parts would have disintegrated after lead got converted into $PbCO_3$ and $Pb(OH)_2$.

Owing to the low melting point and other physical properties molten lead bath is being used even today to heat steel components and as a quenching media during patenting heat treatment. As suggested by Prakash (1989 b) molten lead bath might have been used to heat the square iron rods bundled together to the forge welding temperature and shaping the massive iron components of the bell capital , and during this process some lead might have got trapped in the crevices .

While discussing the corrosion resistance of iron pillar due to the formation of duel layer of iron phosphate and iron oxides. Balasubramaniam has suggested that the ancient iron smelters were in know of the corrosion resistance imparted by phosphate coating i.e. H_3PO_4, $H_3PO_4.4H_2O$, and they were capable of producing iron with controlled Phosphorous content.

His claim seems to be incorrect because of the following reasons:-

1. The iron ore found in India has very low phosphorous content.
2. There was no analytical facility developed at that time and the Indian smelters could not have recognised the iron ore rich in phosphorous by visual examination.
3. Presence of uncontrolled phosphorous is known to affect the mechanical properties of wrought iron and its phosphorous content can not be decided by visual examination.
4. The ancient Indian history does not mention any group associated with the corrosion study nor such study might have been possible before

Christian era. The iron samples recovered during archaeological excavations in the country have generally shown very high level of corrosion.

The bluish reflection from the surface of the iron pillar suggests a very simple process of heat tinting. The ancient black smiths might have observed thermal blue colour on the iron surface developed during its heating (at ~300°C) and they might have treated the finished surface of the Delhi iron pillar to develop a shining blue iron oxide film which has with the passage of time got partially oxidised to higher oxides .

In the third chapter the author has reviewed history of introduction of cannon and its manufacture in the country. Although the use of gun powder in fire work and projectiles was known to Indians for a long time but they have learnt its use in guns and cannons from Turks and Mughals. At first the cannons were made using bronze casting technology but latter while the European people experimented with making cast iron cannons the Indian black smiths used their experience in forging iron and its forge welding to design and produce iron cannons. They made these cannons by binding pre-shaped iron rods forming the gun barrel bound together with the help of three to five layers of iron rings shrink fitted one over another.

Balasubramaniam has explained in detail the design and construction of some of the heaviest iron cannons in the world. Between 15th & 19th AD there seems to be a spurt in the design and manufacture of iron cannons in the Indian Subcontinent and many of these guns have been so heavy that they were left in the battle field where they have been lying unattended. Balasubramaniam and his colleagues have begun the arduous task of locating and preparing a catalogue of these cannons. The design features and photographs of some of these guns have been published in this book. This survey on iron cannons of the country has provided an unique opportunity to Balasubramaniam to carryout first hand study of the design features and dimensions of some of the heaviest iron cannons of the world produced by shrink fitting technique. At the end he has mentioned some of the unsolved questions regarding this ancient Indian cannon technology and he has drawn the attention of technologists from various fields to take up the task of revival of various aspects of this ancient technology and explore its possible use.

While discussing this ancient manufacturing technology Balasubramaniam has suggested the use of lead filling in the gap between the iron rods forming the gun barrel to make it leak proof during firing. He has probably over looked the low melting point of lead (306°C) and it's high ductility, which will give way under high temperature and pressure, generated by the propellant gas decreasing the cannon's thrust at the time of firing .

Balasubramaniam has begun the fourth chapter by describing various applications of Wootz steel for the manufacture of legendry Damascus swords and daggers having typical macroscopic surface structure known as Damascussin pattern, the hall mark of their excellence. He has also described the use of this steel for the manufacture of war weapons, fire arms, armours and musical strings in the country. He has given the chemical composition of this legendary high 'C' wootz steel and its early Indian history as well as its production by the South Indian and Hyderabad processes. He has also mentioned in detail the European effort to duplicate this steel and to produce swords having similar properties by Pattern welding. This description has been followed by a short mention of the modern studies carried out on ultra high carbon steel by Sherby and Wadsworth and Verhoeven and Pendray on the super plastic behaviour of this steel and its thermo-mechanical forging to reproduce the world famous Damascus pattern and properties of wootz steel swords. At the end Balasubramaniam has tried to analyse the reason for the early death of this legendry steel and revival of interest by the modern technologists.

Balasubramaniam has done yeomen service to the Nation by publishing his research studies on the technological skill of ancient Indian iron and steel makers and black smiths in the form of this volume. This book has aptly shown how a metallurgist could be helpful in the study of archaeological materials to rebuild the past scenario and reveal the ancient achievements . For such efforts the archaeologists of the Nation should collaborate with experts of various disciplines of engineering and technology and provide them with archaeological samples to conduct research studies. Irrespective of the differences expressed in the present review the subject matter of this book presents informative material for general readers and new insight into the past Indian glory for the historians and other scholars.