Metallographic Studies of Iron Pillar, Dhar

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Abstract

The science of metallography has been very helpful to study the constitution and internal structure of metals and their alloys, which influence their physical and mechanical properties. This paper reports metallographic studies of iron pillar at Dhar, to highlight the skill and technology of early Indian ironsmiths, in producing so large and massive a monument.

Introduction

The iron pillar at Dhar, the ancient capital of Malwa, represents a unique feat of metallurgical skill of ancient Indian iron craftsman. The pillar which is palaegrahically assigned to 12th century A.D., has been an object of unceasing interest and curiosity not only to the common people but also for chemists and metallurgists, because of its large size and its remarkably will preserved condition despite its prolonged exposure to evironment. History reveals that the manufacture of iron in ancient India is almost unique in the annals of world's metallurgy of iron and India has been a rich iron producing country right from primordial times. It is unanimously accepted that the ancient Indians perfected their metallurgical skill in producing iron to a great extent which can be judged from this famous iron pillar at Dhar.

The large and massive (original total length being 43'8" and weight 7-8 tons) pillar at Dhar is more than double the height of pillar at Delhi and is supposed to be the largest mass of ancient iron known to the world[1]. This pillar has hitherto failed to receive its due share of praise and attention from the scientifc world as it is lying broken in three pieces. Probably it was intact till 1304 A.D. but reported to be broken in to three pieces by the vicissitudes of war[2]. The major part (bottom of the pillar) is reported to be square in cross section while the middle section is partially square and partially octagonal. The third and the smallest part is octagonal with a circular section at the top end. The whole pillar has a continuous tapper from the bottom to the top and its surface has a very crude finish.

Metallographic Studies

Preparation of Sample

Samples were collected from the end of the smaller pillar lying at *Lat-Ki-Masjid*, at Dhar and were received through Indore division, Indore (M.P.). A small piece of metal specimen was carefully cut with the help of a manual mini hack-saw. Soap solution was used during the cutting of the sample to avoid possibility of alteration of original metallographic characteristics due to frictional heat. The specimen was thoroughly washed with distilled water as well as with organic solvents and allowed to dry completely. It was later mounted in a thermoplastic mount (Phenol resin 202) with the help of a mounting press (Morumoto model-2[illegible]). The mounted sample was polished on a metallographic polisher (Morumoto Model-53194) using different grades of abrasives (aq. suspension of alumina) and polishing cloth[3]. Etching of the mounted sample was done with 2% Nital as per ISI specifications.

Optical Microscopy

Microscopic examinations of both etched and unetched specimens were carried out to study general microstructure as well as the distribution and characterstics of non-metallic inclusions. For this purpose inverted Metallurgical Microscope (Olympus-Pme, Tokyo) was used.

Microstructure

Microscopic examination of the unetched specimen revealed undefined light coloured fibrous structure with numerous slag inclusions. Examination of etched specimen, however, does not distinctly show well defined uniform polyhedral ferrite grains, but microstructure appear to be consisting essentially of ferrite. Some areas show preponderance of dark grey slag pockets of irregular as well as globular morphology. These slag inclusions have been observed to be distributed irregularly across the ferritic matrix (Fig. 1).

Fig. 1 Micrograph showing ferritic matrix and distribution of slag inclusions. 100X

Fig. 2 Micrograph showing ferrite and coarse pearlite and coarse pearlite with slag. pockets 300X

At some places large and irregular stringers of slag inclusions have also been observed. The fibrous structure observed in case of the unetched sample may be attributed to the presence of these irregular slag inclusions[3]. Presence of these localized clustering of large and irregular slag inclusions is unique and is in contrast to normal worked. iron microstructure which usually displays arrays of fine slag fibres. Under normal magnification, the microstructure does not show pearlite but under high magnification, when properly resolved, shows irregularly distributed coarse pearlite towards outer surface (Fig. 2). This shows that the carbon was not completly removed from the iron during the metallurgical process[4].

Non-Metallic Inclusions

Microscopic examination also revealed dispersion of small circular or ellipitical inclusions, presumably oxides distributed in the ferritic matrix or in slag inclusions (Fig. 3 & 4). It has has been observed that some of the inclusions were responding to polarized light and displayed dark reflection while others were not found responding to

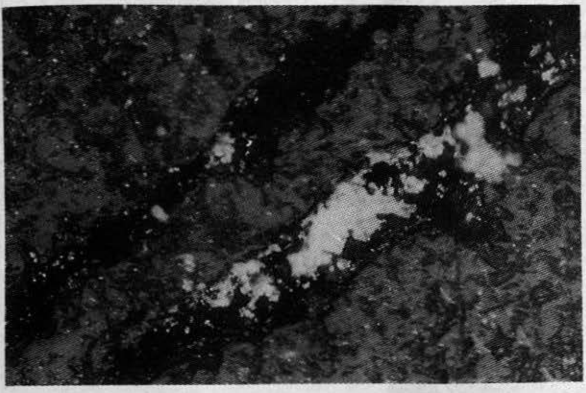

Fig. 3 Micrograph showing Non-metallic inclusions of irregular morphology distributed in the slag, under polorized illumination, 75X

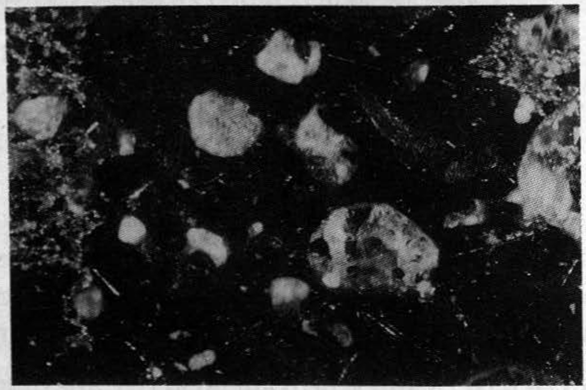

Fig. 4 Micrograph showing circular and elliptical non-metallic inclusions distributed in slag, under polorized illumination, 75X

polarized light. Oxidic slag inclusions, when examined under polarized light also revealed distribution of non-metallic inclusions in its matrix and appeared to be consisted of complex inter growth of either all the three phases Wustite or Magnetite (oxides of iron), Fayalite ($2Fe_20.SiO_2$) and ferrous glass, separately or in combination (Fig. 5).

However, the main phases of slags to be reported are fayalite and ferrous glass where the amount of Wustite is generally lower, but in our studies, Wustite has also been observed as dendrites dispersed

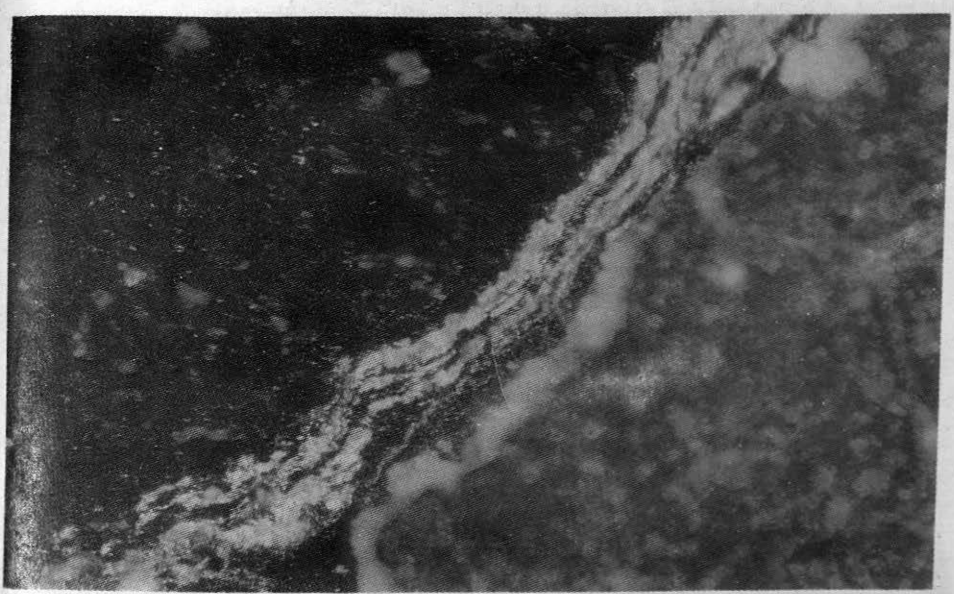

Fig. 5 Micrograph of large tear shape slag & non-metallic inclusion under polarized illumination, 75X

in the dark grey silicious matrix (Fig. 6)[5]. Under plane and polorized illumination, a few strained quartz inclusions surrounded and penetrated by a darker glassy material have also been observed (Fig. 7). This darker glassy material is expected to consist one of the above three phases[6]. Careful examination and isotropic/anisotropic behaviour of inclusions under polorized light suggest that these non-metallic inclusions may not be purely a single component system but are multi component systems, and are expected to contain traces of other non-metallic impurities such as sulphur, phosphorous and manganese etc (Fig. 4).

Scanning Electron Microscopy

SEM study of etched and un-etched specimen also revealed more or less similar characteristics as observed by optical microscopy. Fibrous structure of the metal was clearly visible because of high magnification and better resolution. The appearence of fibrous structure may be attributed to the presence of discontinuties within the soft and ductile ferritic matrix, due to the dispersion of elongated slag inclusions (fig. 8a). Non-metallic inclusions of different morphologies have also been observed, distributed mainly within the slag (Fig. 8b).

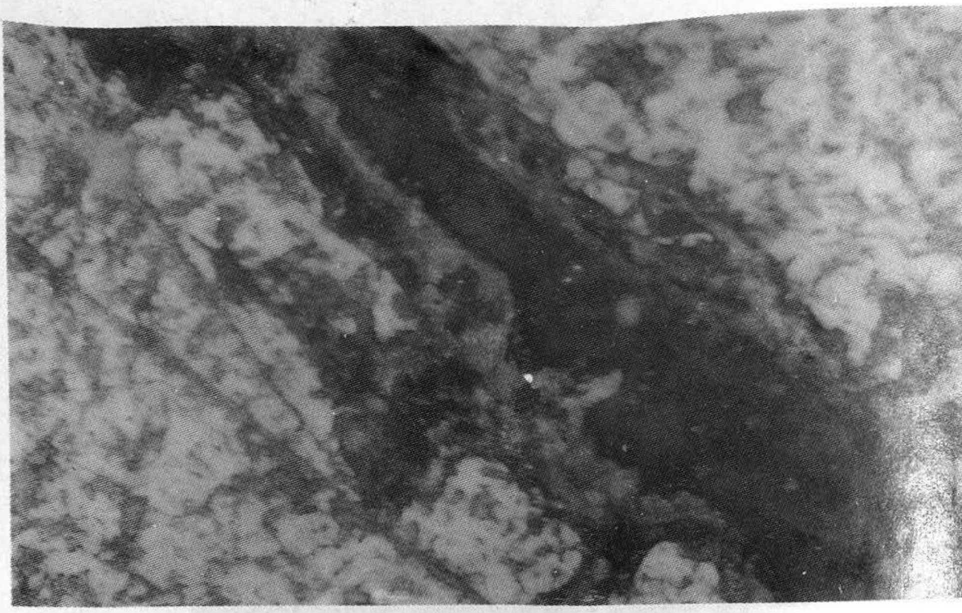

Fig. 6 Micrograph of elongated slag showing fayalitic & wusitic phases under polorized illumination, 75X

Discussion

On the basis of the optical microscopy, as well as SEM study, it is clear that the microstructure of the metal consists essentially of Ferrite. Presence of oxidic slag is characteristic of wrought iron and is the most marked micrographical distinction between wrought iron produced in the liquid state[7]. These characteristics are very much similar to that of the

Fig. 7 Micrograph showing heavily cracked Quartz grain surrounded and penetrated by glassy material under polorized illumination, 75X

microstructure of Delhi iron pillar, which has also been reported to be made of wrought iron[8,9]. The absence of uniform distribution of pearlite is possibly because of low carbon content, as carbon is expected to be removed as much as possible during the metallurgical process to obtain comparatively pure iron. As the carbon content decreases the metling point of the mass increases and pure iron is obtained[10]. However, since the analytical studies are not reported in this paper, it is also possible that as reported in case of iron, due to segregation of phoshorous and diffusion of carbon, the metal has become poorer in carbon content pillar, Delhi.

Detailed micrographical studies of oxidic slag distributed in the ferritic matrix of the metal, also reveal the structure expected for puddling slag. The dominent constituent appears to be fayalite, and iron oxide is most likely present as magnetite and wustite, depending upon the conditions prevalent during the metallurgical process. Presence

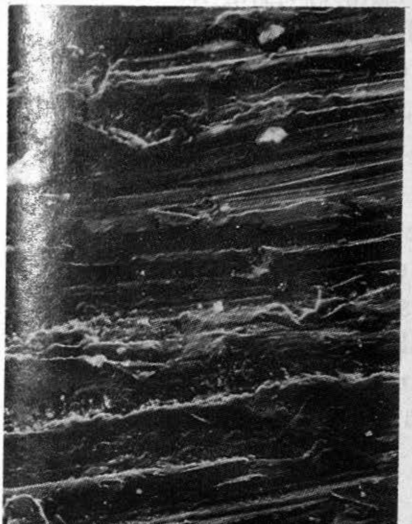

Fig. 8a SEM Micrograph Revealing Fibrous structure of the metal & distribution of elongated slag.

Fig. 8b SEM Micrograph Non-metallic inclusions distributed in ferritic and slag matrix

of non-metallic inclusions, particularly silica, is also an additional characteristic of puddling slags. However, in the absence of proper study, it is very difficult to infer the crystalline form, but morphological features suggest that quartz may also be present in the form of its high temperature polymorphs-tridymite and cristobalite[6]. This is also supported by Fig. 7, in which quartz particles in early stage of a reaction, that have been arrested perhaps by premature cooling.

Conclusion

Metallographic and microstructural characteristics of the Dhar pillar iron sample, are indicative of wrought iron origion. The distribution of silicious slag in the iron matrix is not uniform, and localized region show high density of large and irregularly shaped slag particles. Absence of uniform distribution of pearlite indicate that the metal was poorer in carbon content and wrought iron was obtained from iron ores by direct process. Above studies also indicate that unlike Delhi iron pillar, Dhar pillar was not cast but fabricated by forging and welding large quantities of wronght iron. Forging was however, inadequate as suggested by localized distribution of coarse slag pockets, unlike modern day wrought iron which contains fine dissemination of slag fibres in the iron matrix.

Acknowledgements

The authors express their sincere gratitude to Dr. R.K. Sharma, Director (Science), Archl. Survey of India, Dehradun, for his expert, revealing and inspiring guidance throughout the study. The authors are also thankful to Shri K.S. Rana, Suptdg. Archl. Chemist, Indore Division, Indore, and Shri A.K. Sinha, Suptdg. Archaeologist, Bhopal Circle, Bhopal, for providing samples and valuable information regarding the Dhar pillar.

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