Ancient Indian Iron*

By S. C. BRITTON, Salters Fellow, University Metallurgical Laboratories, Cambridge

METHOD OF PRODUCTION

THE careful investigation of I. E. Lester[16] and of A. K. Coomaraswamy[17] indicate that iron was produced in ancient India by direct reduction from the ore, and that the process was precisely similar to that employed by primitive Indian craftsmen down to comparatively recent times. The description given by Prof. Henry Louis[18] of the process which he witnessed at Jubbulpoor may be quoted to give an idea of the method of working:

"The furnace was built of dried clay along the edge of a trench some 3 feet high above the trench; the bottom of the hearth was about a foot above the bottom of the trench so that the furnace was about 5 feet high inside; it was about 10 inches square at the mouth, but widened out to about double that size at the hearth. The back and side walls were about 2 feet thick, but the front wall, facing the trench, was only a couple of inches in thickness. Through that passed a couple of tuyeres, made of dried clay, about 2 feet long, pierced with a 2 inch hole. The blast was supplied by means of a pair of circular goat-skin bellows worked by hand; a roof of branches and leaves was built over the bellows to screen them (and the man blowing them) from sparks. The furnace was filled with charcoal, and, after that had been ignited, small baskets of ore and charcoal were thrown on alternately at intervals of about half an hour. After some ten or twelve hours' work, the thin wall was broken down, and a bloom of some 70 lbs. weight was got out. That rough bloom was cut into pieces, heated up in a primitive forge and hammered into flat cakes, in which form it was sold."

Lester[16] is strongly of the opinion that the quality of Indian iron is due to the cunning of the smith in making a selection from the metal produced from the ore and to his operative skill.

There seems little doubt that the ore used was generally the nodular hæmatite which is fairly widely distributed in India. A typical analysis given by Hadfield[19] is SiO_2, 9·14; Al_2O_3, 9·85; Fe_2O_3, 72·39; FeO, 0·22; moisture, 8·40; S, nil; P_2O_5, 0·05.

The extremely low sulphur content of all the ancient specimens analysed shows that a pure charcoal was generally used for smelting and treating the metal.

RESISTANCE TO CORROSION OF ANCIENT INDIAN IRON

Pliny, the Roman historian[20], stated that there was in existence at the city of Zengma, upon the Euphrates, an iron chain by means of which Alexander the Great constructed a bridge across the river; the links of the chain which had been replaced had been attacked by rust, while the original links were quite exempt from it. This belief that the iron of to-day is inferior to that of yesterday has echoed down the ages, and most observers have been content to repeat it to explain the state of preservation of ancient Indian iron. Several suggestions have been made as to the direction in which the alleged superiority lies. Hadfield, dealing with the Delhi pillar, regards the purity of the metal and absence of inclusions as responsible for its preservation. Protagonists of copper steels have alleged that a small percentage of copper might be responsible. A. S. Cushman, discussing Hadfield's work on Sinhalese iron[21], reported that old wrought iron nails which had shown almost perfect resistance to corrosion for a hundred years in Virginia, had a very similar composition to the Sinhalese specimen, having an analysis C, 0·03; Mn, 0·06; P, 0·205; Si, 0·121; Cu, 0·027. He doubted whether the resistance of ancient steels was due to the presence of copper in them; the three Sinhalese specimens examined by Hadfield showed percentages 0·012, 0·090 and 0·119, but all were corroded in similar fashion. Perhaps the combination of low sulphur and low manganese with high phosphorus produced corrosion resistance.

Wallace reported[22] the general freedom of Indian iron from rust and mentions that he has noticed that modern native-made iron forged on a stone anvil does not rust like English iron. "The iron-work of the car on which the Gods of the Kulu valley take the air has a fine brown patina and no rust flakes. It is all charcoal iron." Discussing this communication, Carulla suggested that forging on a stone anvil might "Siliconide the skin of the iron" and thereby make it resistant.

Rosenhain[23] suggested that much ancient iron contained a large amount of cinders in layers so that corrosion proceeded until a cinder layer was reached and then ceased. Also Desch[24] noted that many specimens looked as if coated with a fine adherent layer of slag. However, Hadfield has been unable to find any evidence of such coatings on the materials which he has examined.

Several observers have been inclined to believe that there is not inherent superiority in the metal over modern products. Graves, discussing the paper of Friend and Thornycroft[25], commented that, of the many specimens of ancient iron which he had seen in India, some were rusted and some were not, the difference apparently depending on the situation. In the same discussion Prof. Louis suggested that the preservative factor was essentially climatic.

Friend[26], discussing the Delhi pillar, states that the composition of the metal "tends toward the reduction of corrodibility but does not suffice to explain the general immunity of the pillar from corrosion. This suggests that the resistance to

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*(*Continued from p.* 240.)

corrosion is due to the surface condition of the metal, which in other similar cases is usually known to be highly polished". He goes on to mention "the ancient custom of anointing the pillar with butter at certain religious festivals" as a contributory cause of a resistant surface.

There appears to be some confusion amongst the various views expressed as to whether the various well-preserved specimens have suffered corrosion at a remarkably slow rate or have suffered no corrosion at all, and it seems worth while to consider what could be the reason of either alternative. If there has been no corrosion, three possible explanations arise: that the metal is by reason of its composition not susceptible to attack, that it is covered by an oxide scale, formed in manufacture and never broken, or that the rain falling or moisture condensing on the metal is alkaline.

It seems unlikely that the original scale should never have been broken, especially, for example, on the fractured surfaces of the Dhar pillar.

R. B. Mears has recently, at Cambridge, used the method[27] developed by himself and Dr. U. R. Evans to compare the susceptibility to attack of modern iron and steels with that of a specimen of the Dhar pillar, the gift of Sir Edwin Lutyens to Prof. A. Smithells, who kindly allowed its use for the experiment. The specimens used were all ground, the final grinding being carried out in identical fashion for all materials. The method of the experiment consists essentially in the determination of the proportion of drops of distilled water (condensed in quartz) which cause rusting of the material in 24 hours under an atmosphere having pure oxygen and pure nitrogen in equal parts. The figures obtained were:

Pure Carbonyl Iron	0	per cent
Electrolytic Iron	8·3	,, ,,
Modern Wrought Iron	82·8	,, ,,
Modern Mild Steel	87·9	,, ,,
Dhar Pillar Iron	100·0	,, ,,

Although the various materials used may not be typical of their classes, and the Indian specimen may not be from the best part of the pillar, the numbers do show that the ancient iron cannot well be less susceptible to the commencement of corrosion than the modern products. The fact that corrosion began so readily under 'pure' conditions suggests that the Indian pillars have been corroded to some extent, unless the rain which falls on them is alkaline.

The results obtained in recent work show fairly definitely that the idea that special resistance to atmospheric corrosion can be conferred on iron or steel by eliminating minor constituents (particularly carbon and manganese) is wrong, though there is considerable evidence to show that physical unsoundness or the presence of sulphide inclusions causes premature failure.

In American tests[28] forms of iron low in carbon and manganese faired somewhat badly as compared with the steels. U. R. Evans and the author[29] compared the resistance of a pure electrolytic iron having C, 0·03; S, 0·005; Mn 0·04; P, 0·02; with that of a steel having C, 0·026; Si, 0·14; Mn, 0·57; P, 0·018; to corrosion in the atmosphere of Cambridge. Purity (that is, the absence of a second phase) and surface 'smoothness' undoubtedly retarded the early development of rust, but after six months, any difference which existed between pure iron and good mild steel in the unpainted condition was in favour of the steel.

It has to be remembered that the Indian irons are really wrought irons, and there is some evidence to show that under modern English conditions, wrought irons can give superior service to steel. For example, many structures, such as the High Level Bridge at Newcastle, erected in 1845, the Conway Tubular Bridge, erected in 1846, and the Menai Tubular Bridge, erected in 1852, are still in service, though it is possible that their preservation is the result of effective painting.

The exposure tests of Evans and the author[30] at Cambridge "point to the good behaviour of wrought iron. This is apparently due to the infrequency of specially susceptible points, the greater tendency to passivity and the convenient character of the scale". However, it remains true that in the English or American climates the rates of corrosion of wrought iron, good steel and 'pure iron' are substantially of the same order of magnitude, and it is safe to conclude that a slow rate of attack of such objects as the Delhi pillar is not due to their composition alone. It seems probable that climatic conditions have been the preservative factor.

For centuries after the erection of the Delhi pillar, the atmosphere of its neighbourhood must have been substantially free from pollution by any products of combustion, and its distance from the sea rendered the presence of much salt in the air unlikely. The dryness of the climate was sufficient to ensure that the pillar was only wet during the fall of rain, which must have been effectively distilled water. In these circumstances the initial rate of corrosion of the pillar would be extremely slow. W. H. J. Vernon[31] showed that an initial period of exposure of iron to a relatively non-corrosive atmosphere greatly reduced the rate at which it was corroded when the conditions were made more severe; the Indian columns may have benefited by this effect in being erected initially during the 'dry' season.

The extremely slow attack may well have built up a very closely adherent and complete layer of rust which, being free from hygroscopic salts and in a hot climate did not, as rust often does, promote attack by keeping the metal moist, but actually served to shield the metal and reduced still further the rate of attack. It may be supposed that the rust layer became in the course of centuries sufficiently protective to withstand the arrival of a more polluted atmosphere. The bronze-like patina described so often may well be due to this compact layer of ferric hydroxide.

It is worth noting that in parts of India to-day, modern steels are giving excellent service. Indian railway authorities state, for example[32], "The conditions on the Railway are tropical and there is very little corrosion. Steel trough sleepers removed from the main line after 35 years service still retain a great deal of the original mill-scale" and "Iron covered goods wagons built in 1883 are still free from corrosion" but "Plates which give over thirty years of life in this part of India do not last more than a few years in Burma or on the Bombay Coast".

Thus, the most probable explanation of the preservation of the Delhi pillar seems to be the combination of 'purity' of atmosphere and the climate. The other specimens of Indian iron have not all had the same favourable conditions although the metal is similar and so a good deal of rust is found on some of them. The specimens of ancient iron found in countries other than India may be said in general to be in a state of preservation varying with their climatic environment. Thus many specimens, preserved excellently, have been excavated in Egypt[33]; here conditions have been dry, stretches of the desert are alkaline, and the atmosphere is unpolluted, though it has also been suggested[34] that the iron is of meteoric origin and owes something of its preservation to a high nickel content. On the other hand, specimens of Roman iron found in Britain are found to be extremely rusty, although Friend and Thornycroft[35] comparing the still metallic part of a corroded nail with a modern mild steel found that the ancient iron was the more resistant to corrosion of the two.

On the whole, it must be concluded that, although we should regard the operative skill and capacity for hard work of the ancient smiths with admiration, we cannot really expect to solve our corrosion problems by contemplation of their products.

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[16] Presidential Address to the Staffs. Iron and Steel Inst., Sept. 30, 1911.

[17] "Medieval Sinhalese Art".

[18] *J. Iron and Steel Inst.*, No. 1, 129; 1912.

[19] *J.I.S.I.*, No. 1, 152; 1912.

[20] Pliny, Book XXXIV. Chap. 43.

[21] *J.I.S.I.*, No. 1, 179; 1912.

[22] *J.I.S.I.*, No. 1, 84; 1908.

[23] *Trans. Far. Soc.*, **11**, 236; 1916.

[24] *J. West of Scotland I.S.I.*, 1913–14.

[25] *J.I.S.I.*, **122**, 237; 1925.

[26] "Iron in Antiquity", p. 147.

[27] *Proc. Roy. Soc.*, 1934.

[28] Report of Com. A 5, *Proc. Am. Soc. Test. Mat.*, **27**, Part 1; 1928.

[29] *J. Soc. Chem. Ind.*, **49**, 173, T; 1930.

[30] *Trans. Electrochem. Soc.*, **64**, 48; 1933.

[31] *T.F.S.*, **23**, 164; 1927.

[32] "Corrosion Committee of Iron and Steel Inst. First Report (1931)", p. 18.

[33] Hadfield, *T.F.S.*, **11**, 183; 1916.

[34] T. A. Rickards, *J.I.S.I.*, No. II, 333; 1929.

[35] *J.I.S.I.*, **11**, 225; 1925.

Obituary

M. B. Baillaud

BENJAMIN BAILLAUD was born in 1848, a year of revolutions, and his peaceful life, which came to an end on July 8 last, was crossed by two wars which shook France to her foundations. Passing through the École Normale, he became an assistant to Leverrier at the Observatory of Paris, and also his substitute at the Sorbonne. After the defeat of France in 1870, Baillaud, then at the meridian of his energy and clearness, shared in the immense revival of France which had its place in the sciences, as well as in other directions. Sent to Toulouse, to reform the Observatory in succession to Tisserand, and afterwards as dean of the Faculty of Sciences, he performed these duties with singular zeal and effectiveness. He modernised the Observatory and brought many men, since famous, to the University; in the former respect we may mention only, as an instance of his foresight, that he developed as a pioneer, celestial photography. He also established at the greatest height then known, more than 9,500 ft., an observatory, chiefly, of course, meteorological, on the Pic du Midi de Bigorre, in the Pyrenees.

Chosen director of the Observatory of Paris in 1907, and so titular head of French astronomers, Baillaud added to his previous work on celestial photography an interest especially in time determination and distribution, a matter in which his friendship with Ferrié, then in charge of the station at the Eiffel Tower, assisted. The Observatory of Paris has a long and notable history, and is housed in Paris in a celebrated building, which is scheduled among the historic monuments of France. It was in Baillaud's time, however, somewhat out of date in equipment. He had, fully formed, complete plans for the renovation of the observatory, but circumstances prevented a repetition of his work in re-equipment, as at Toulouse, as it also prevented his repeatedly expressed desire for retirement.

The latter was not the desire of the astronomers however. When the sixth Congress met in 1909 to regulate celestial photography and produce the astrographic catalogue and the Carte du Ciel, Baillaud was chosen president. Later, with Ferrié, two successive congresses were summoned at the instance of the Bureau des Longitudes, in 1912 and 1913, to deal with time distribution, which was initiated, so far as Europe was concerned, and has since been maintained, from the Eiffel Tower, and afterwards from other more powerful stations; the first of these congresses chose Baillaud as its president, and he kept the organisation in being right through the War, though none of the countries which had initialled the document creating the Bureau de l'Heure ratified it. He only resigned this charge, as he resigned that of the Carte du Ciel—without ceasing an interest in them—in 1919, when he was chosen as the first president of the International Astronomical Union;