

APPENDIX II. TO SIXTH REPORT TO THE  
ALLOYS RESEARCH COMMITTEE.

MALLEABLE IRON CASTINGS.\*

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By MR. C. O. BANNISTER, ASSOC. ROYAL SCHOOL OF MINES.

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For the cheap manufacture of iron articles requiring a fair amount of strength, it has been found convenient to first cast them and then to partially decarburise the castings by an oxidizing cementation treatment, thus producing a coating of malleable iron over a core of brittle cast-iron. The articles thus made are known as malleable iron castings, malleable iron or run steel. This process is specially useful for small articles of intricate shapes. Fairly large articles, such as propeller shafts, etc., have been made by this process and a subsequent operation for case-hardening.

Although this process was described by Reaumur in 1722, patents were only taken out in 1804 by Lucas and in 1850 by Brown and Lennox.

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As modifications of the process, mention may be made of the method proposed in 1828 by Karsten, which was to submit iron castings to a glowing heat in a current of air; and of Tunner's method, proposed in 1846, which was to expose iron castings to a red heat in boxes filled with sand and allowing a regular admission of air; the action in this last method was sometimes aided by the use of substances which provided oxygen, such as haematite, hammer scale, etc. Briefly, the process, as generally practised, consists of heating the castings packed in haematite to a bright red heat for several days.

The castings of the best Cumberland white or grey iron are made in sand moulds with or without chills, and packed with haematite in iron boxes. The haematite is crushed and passed through a 70- or 80-mesh sieve and mixed with used haematite from a previous operation, because the fresh haematite alone is too vigorous in its action. The mixture generally used consists of two-thirds used and one-third fresh, sometimes a mixture of half and half is used. Used haematite is sometimes reoxidised by the addition of a little sal-ammoniac and spreading it out in the open air.

The boxes, cast from a special mixture of white iron and scrap, vary in size, according to the size of the castings to be annealed, and may have a circular or rectangular horizontal section.

The furnaces consist of rectangular chambers, with dome-shaped roofs, built in rows, each communicating with a flue which leads to a stack. The furnaces may be coal or gas-fired; the sketch, Fig. 192, Plate 44, represents a coal-fired furnace, such as is generally used in the Midlands. The middle portion of the bed is raised, thus providing two passages down the sides for the fires. The boxes containing the castings are placed on this raised floor, three or four in each pile, the joints between them being sealed with fire-clay or wheel swarf, and the top box is completely covered with the same substance. Each furnace holds from twelve to twenty boxes. After the fires have been started, a bright red heat (between  $1,000^{\circ}\text{C}$ . or  $1,832^{\circ}\text{F}$ . and  $1,100^{\circ}\text{C}$ . or  $2,012^{\circ}\text{F}$ .) is maintained during the day; at night the ovens are damped down and only a dull red heat obtained, until the fires are again made up in the morning. This heating goes

on for several days, from five to nine according to the size of the castings and the degree of decarburization desired; after the furnaces have been allowed to cool for one or two days, the boxes are withdrawn and unpacked. The middle boxes of each row are found to work most evenly, and the most important work is always packed in these.

The great objection, which prevents this process from being much more extensively used, is the presence of small quantities of slag and blow-holes in the castings, which greatly reduce their strength, introducing an element of unreliability.

Much experimental work has been done in order to investigate the changes which take place in the composition of the iron during this process, the increase of strength, the most suitable cement, and the correct time of cementation.

The most important conclusions arrived at are :—

1. A malleable casting always contains amorphous carbon.
2. A casting may lose carbon and still remain fragile if the remaining carbon is not in the form of graphite, or if the initial quantity of graphite is not increased.
3. A casting may become malleable without a sensible loss of part of its total carbon.
4. In general practice the castings lose on the total carbon, and some of the combined carbon is converted into finely-divided graphite or temper carbon.
5. The castings generally lose some sulphur, which is found in the haematite in such a form as to evolve sulphuretted hydrogen on treatment with acids.
6. As a rule the other constituents of the castings are not altered to any appreciable amount.

The following work has been done to show by means of analyses and photo-micrographs the changes which take place during the operation. The preparation of the samples was left in the hands of a practical man, so the results are such as would be obtained in commercial objects.

Fig. 193, Plate 44, is a photograph of a cross section of the original bar highly polished, etched and magnified about three times. The analysis of this gave the following figures :—

Combined carbon	.	.	.	.	.	2.53 per cent.
Graphitic carbon	.	.	.	.	.	Nil.
Sulphur	.	.	.	.	.	0.36 „ „
Phosphorus	.	.	.	.	.	0.036 „ „
Silicon	.	.	.	.	.	0.707 „ „
Manganese	.	.	.	.	.	0.185 „ „

Fig. 194, Plate 44, is a photo-micrograph of the same iron magnified 1,600 diameters, and shows cementite and confused pearlite or sorbite. Sorbite is practically pearlite in which the laminae have not separated, and cementite is carbide of iron.

Fig. 195, Plate 44, is a photograph of a cross section of the bar after being annealed in haematite, polished, etched and magnified about three times. This shows how the decarburization has taken place from the outside, with the formation of graphitic carbon towards the centre. The analysis from the whole of a drilling through the bar gave:—

Combined carbon	.	.	.	.	.	0.74 per cent.
Graphitic carbon	.	.	.	.	.	1.33 „ „
Sulphur	.	.	.	.	.	0.33 „ „
Phosphorus	.	.	.	.	.	0.04 „ „
Silicon	.	.	.	.	.	0.667 „ „
Manganese	.	.	.	.	.	0.192 „ „
Total carbon	.	.	.	.	.	2.07 „ „

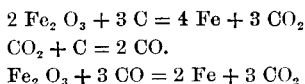
On comparing these figures with those given before, we find that the total carbon has been reduced from 2.53 per cent. to 2.07 per cent., that 1.33 per cent. carbon originally in the combined state has been converted into the graphitic condition, that the sulphur has been reduced by 0.03 per cent., and that the other constituents have only slightly varied.

The next set of photographs, Figs. 196 to 208, Plates 44 to 46, are a series taken from the outside to the centre of the annealed bar magnified 1,600 times, showing the gradual change in the iron. The graphitic carbon is so finely divided that, even at this magnification, it is difficult to detect.

*Theory of the Process.*—The temperature of the annealing furnace is carefully kept somewhere between 1,000° C. (1,832° F.) and 1,100° C. (2,012° F.), and it is a well-known and fully accepted fact that at a temperature of 1,050° C. (1,922° F.) cementite ( $\text{Fe}_3\text{C}$ ) is dissociated into its constituent elements and produces a solid solution of free carbon in iron. Dr. Stansfield \* has shown that when cast-iron is heated and allowed to cool slowly the carbon separates out as graphite, being less soluble in this form than when present in the form of cementite. At the annealing temperature, the cementite is dissociated and the graphite is left in a very finely divided condition. The reason the graphite does not crystallise is probably because: firstly, there is a certain mechanical opposition in the mass, caused by the separation of the graphite which occupies more space in this condition than it does when in solution; secondly, there was no crystalline graphite originally present in the bar which would have formed nuclei around which more graphite could collect.

On referring to the diagram, Fig. 209, Plate 47, showing the distribution of carbon in the annealed bar, it is found that after a certain point 0·5 per cent. carbon is reached, although the graphite increases from this point to the centre of the bar by 1 per cent., the combined carbon only increases by 0·3 per cent. The reason the amount of combined carbon is less near the surface of the bar is because the mechanical opposition to its dissociation is not so great, and therefore allows of the separation of the graphite to a greater extent.

During the decarburization of the bars there are two opposite actions continually at work. On the one hand there is the oxidising action of the cement (in this case haematite) on the outside of the bars, oxidising the carbon by solid contact, and also by gaseous diffusion according to the equations:—




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\* Journal, Iron and Steel Institute, II, 1900, page 317.

thus producing iron free from carbon (ferrite). On the other hand there is a store of carbon towards the centre of the bar in the form of non-crystalline graphite, which is continually recarburizing this ferrite by solid diffusion. These actions continue as long as a temperature of  $1,050^{\circ}$  C. ( $1,922^{\circ}$  F.) is maintained, but on lowering the temperature they cease and the final product is as shown in Fig. 194, Plate 44.

The Appendix is illustrated by Plates 44 to 47.

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