character of the rope, or that the weight the rope has had to carry was excessive. In either case, the surface of the crown wires spreads out, with the natural consequence that the surface layers become brittle and snap, and the fracture then travels completely through the wires. This crushing can be readily detected by the microscope. If the wires are drawn to a maximum degree of tenacity, very little surface flow of the steel produces the same effect as drawing the wire to the point of brittleness.

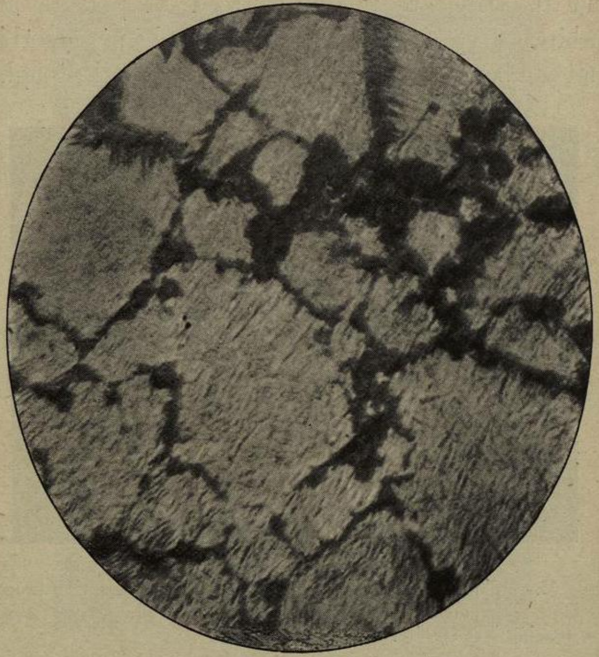

Fig. 106.—Same as fig. 105, magnified 300 diams., showing the needle structure of martensite and troostite (dark).

Local microscopic pitting by corrosion in wire ropes not infrequently leads to fracture of the surface wires even before the ropes are put into use. The microscope is useful in detecting these.

Sometimes ropes during service are subjected to sufficient friction momentarily to heat the surface layers to redness, which, followed by chilling, leaves them in the hardened state—so hard, in fact, that they cannot be filed or scratched with a needle. The steel is converted into martensite, and this can readily be discovered under the microscope. Wires in this condition break when the rope passes over a pulley.

Fig. 107.—Crown wire of a winding rope made brittle by friction heat and rapid cooling. The white band is martensite. × 50.

There are many cases, however, where wire ropes fail, in which the causes of fracture have not hitherto been explained. Such failures occur in the best ropes as well as in ropes of inferior quality. Chemical and microscopical examination and the most rigid mechanical tests do not lead to any explanation (figs. 105-110).

Cast Steel before and after Forging.—It is only by aid of the microscope that one can invariably tell whether steel has been forged or not.

In steel castings one sometimes finds, in material which is apparently quite sound, minute globular blowholes or bubbles. These are never present in forgings unless the hammering has been slight, when in such case the bubbles become flattened or elongated if not quite closed. In all steel castings one finds particles of manganese sulphide and sometimes manganese silicate and slag (figs. 111 and 112). These, on the average, are equiaxed, whilst in the forged steel they are distorted, and on the average are longer in one axis than the other. It is necessary to examine sections cut from two or more directions so as to obtain plane surfaces at right angles to each other, for if only a single section is cut at right angles to the direction of extension the particles will probably appear equiaxed, which might lead to an erroneous conclusion. Examination of the other sections will eliminate such a source of error.

Fig. 108.—The same as fig. 107 after attempting to bend. × 50.

It is a remarkable fact that whilst the sulphide of manganese particles are plastic and flow with the steel during forging, silicate slag, if present in relatively large masses, frequently does not, as it breaks up and shatters and is found in that condition in the cold steel. The presence of these broken-up particles is ample evidence that the steel containing them has been forged. The relative length, as compared with the breadth of the enclosed particles, gives us some idea as to the amount of work put upon the cast steel, unless the particles are exceedingly minute, for in such case they do not extend to anything like the same extent as the metal which flows over them, possibly because the inclusions are not so plastic as the steel. Thus one may find the ratio of length to breadth of manganese sulphide particles in steel rails as 1 to 5 when the steel has been extended in length by 1 to 20 or more.

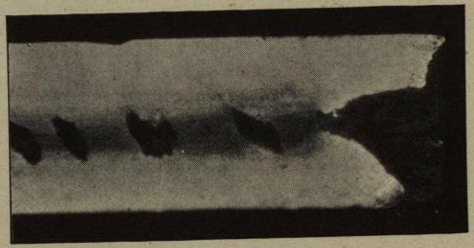

Fig. 109.—Longitudinal section of cuppy wire after etching, showing segregation in the central axis. × 10.

It is usual to find the sulphide of manganese embedded in the ferrite lines or bands, and when it is, we may be certain that the phosphorus is concentrated in the same region, for they associate and are concentrated together during the final solidification, and do not possess the power to diffuse like the carbon.

Phosphorus, carbon, and iron, although they mix together freely when the metal is molten, separate somewhat in the cold steel, and in cooling down the carbon diffuses into the parts more free from phosphorus. On reheating to 900° C., or above, a portion of the carbon diffuses back again into the phosphorised portions, and may be retained there if the metal is quenched in water, but if time is allowed in cooling down it diffuses back again to its original position into the portions containing the lesser amounts of phosphorus.

Fig. 110.—Microscopic corrosion pits in the crown of a wire rope which had been kept in stock in a warehouse for a long time. After removal of the wrapping, several wires were found to be broken at spots where such corrosion pits had formed. × 50.

Case Hardening.—The micro-examination of case-hardened iron or steel is most helpful for the determination of the depth of carbon penetration, the proportion of carbon in the hardened skin, whether or not the case-hardened metal is rich or poor in carbon, and whether, owing to faulty treatment, there has been superficial decarburisation.

Fig. 111.—Steel casting which had been slightly forged. Note the ovoidal form of the manganese sulphide. × 300.

After examining microscopically and noting the depth of the dark or hardened portion of the polished and acid-etched section, the specimen, or another portion of it, should be heated in charcoal powder to 760° C.—just above the recalescence point—and should be slowly cooled in the crucible. This will not

carburise the metal, but the carbon of the hardened steel will be converted into the pearlitic condition. By polishing, etching, and examining, a close approximation of the percentage of carbon can be obtained at the surface, and at progressive distances from the outside to the inside where there is no carbon introduced by cementation. This is a much more rapid and easy method than chemical analysis, and it is of great value.

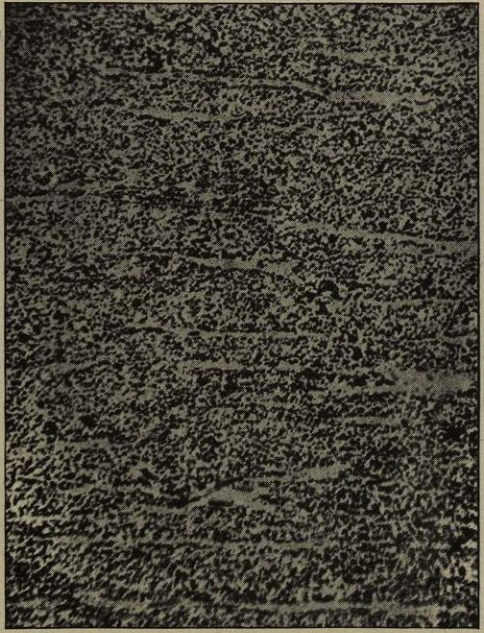

Fig. 112.—Steel casting forged so as to double its length. Note that the ferrite bands indicate the direction of extension. × 50.

If the section is cut at a known angle to the surface, and the specimen be polished and etched, the structure can be the more readily studied. As it is impossible to saw through the hardened skin, the metal may be ground down to the necessary angle on an emery wheel, taking care that during grinding the metal does not get to a tempering heat. After annealing, of course, the metal can be readily sawn (fig. 113).

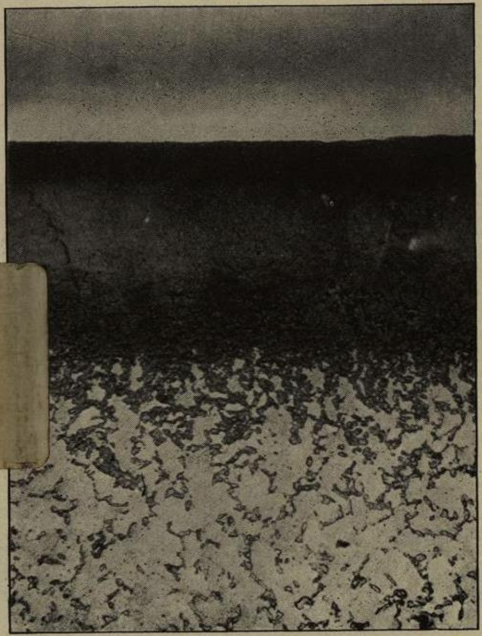

Fig. 113.—Case-hardened motor gear wheel strongly etched with strong acid, showing depth of carburised layer (dark) and that the steel below contains very little carbon. In the best gear wheels the carburised layer is much thicker than that shown in this example. × 35.

Electric Repairing of Steel Castings.—When an electric arc is allowed to play on a mass of cold steel and the current of electricity is turned off, the heat is conducted from the heated steel by the surrounding cold steel, and the part heated and chilled

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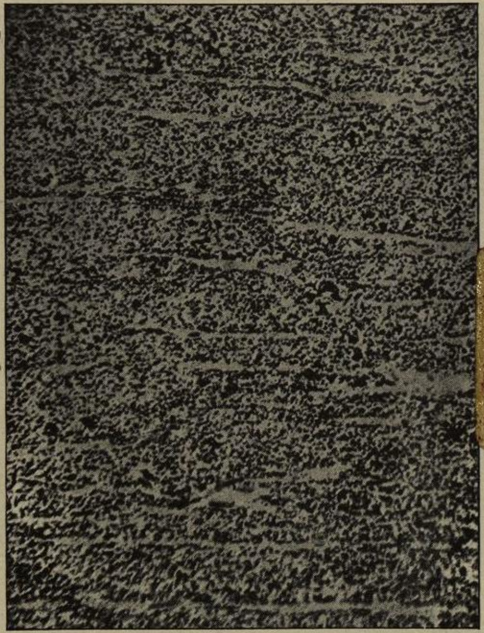

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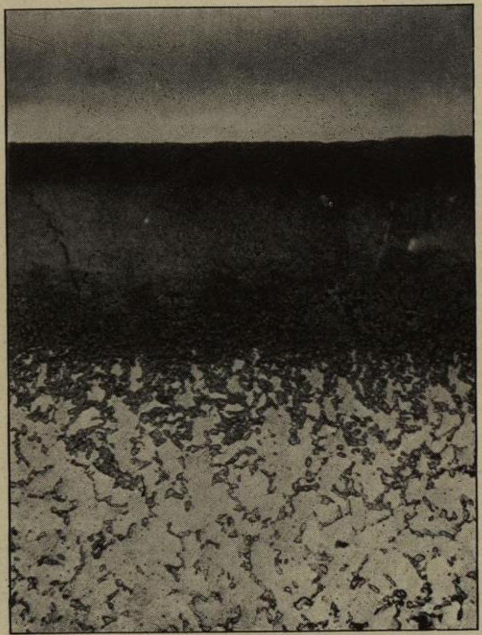

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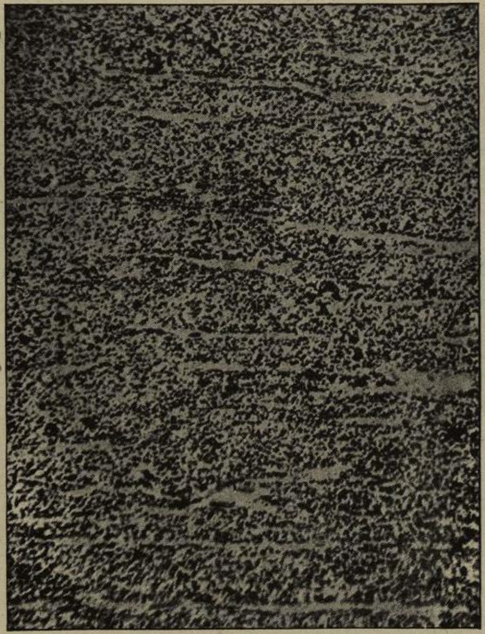

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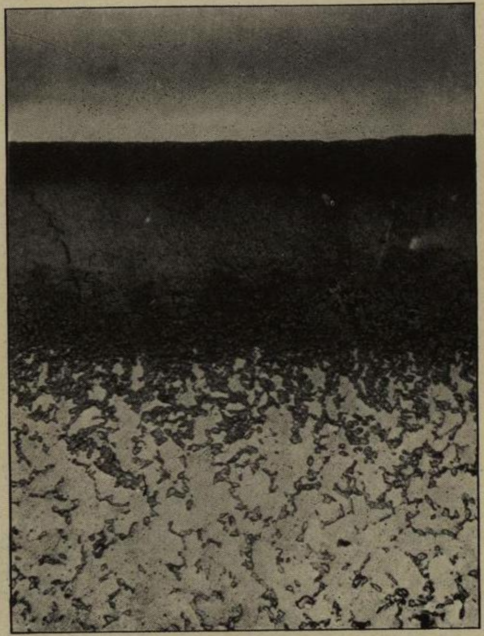

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Electric Repairing of Steel Castings.—When an electric arc is allowed to play on a mass of cold steel and the current of electricity is turned off, the heat is conducted from the heated steel by the surrounding cold steel, and the part heated and chilled

in that way becomes very hard. The steel is converted into martensite.

On roughly polishing the metal and etching it with dilute reagents, the hardened area remains white, whilst the surrounding mass of unhardened steel assumes a grey or brown colour. On etching with 20 per cent. solution of nitric acid in water the martensite becomes intensely black.

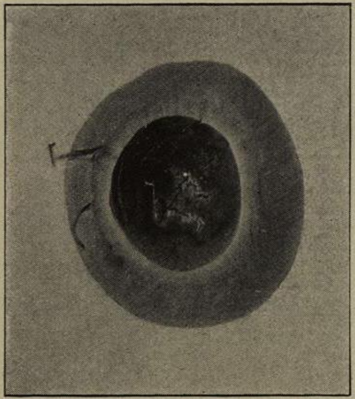

Fig. 114.—Surface of a rail head containing about 0·7 per cent. carbon on which an electric arc was allowed to play for half a second. It was polished, and etched with dilute nitric acid 20 per cent. The black ring is martensite or hardened steel. The black centre is the part melted and covered with oxide scale. The white inner ring is decarburised steel. × 2.

In castings which have been repaired by filling in the cavities with steel melted by the electric arc, such steel is always practically carbonless, whilst the surrounding steel becomes converted into martensite or troostite. On roughly polishing the surface and etching with a strong reagent, the steel filling remains white, the adjacent steel becomes black, whilst the unaltered steel beyond turns to a grey or brown colour. If the casting be annealed afterwards, the martensite changes back to the soft pearlite condition and does not etch to a black colour, but the fillings remain brilliantly white. By this etching method, then, one can tell at once whether the steel has been electrically repaired and whether it has been annealed afterwards. Welding by thermite or by the acetylene blowpipe can be equally well detected by the same method (fig. 114).

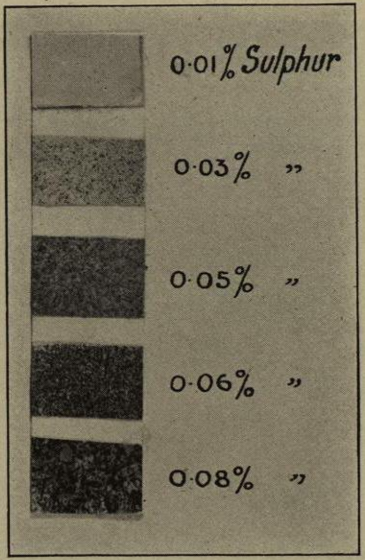

Fig. 115.—Sulphur autoprints of cast-irons containing varying quantities of sulphur. Natural size.

Sulphur in Pig-Iron.—Given the fracture of pig-iron, modern metallographic methods of investigation are useful in supplementing what the fracture indicates. By pressing a piece of polished pig-iron upon a standard piece of bromide paper which has previously been soaked in a solution of 3 parts sulphuric acid in 97 parts of water, and allowing the metal and paper to be in contact for a standard period of time, usually one minute, an approximate idea of the proportion of sulphur present in the iron may be obtained, for the depth of the brown stain of sulphide of silver produced on the paper will be proportional to the amount of sulphur. This is clearly shown in a series of autoprints of pig-irons (fig. 115).

Fig. 116.—Phosphide of iron eutectic in pig-iron containing 1·5 per cent. phosphorus.

This method, modified by Baumann from one invented by Professor Heyn, is now in constant use in many of our most progressive steelworks and engineering establishments for determining whether there is segregation of the sulphur in the steel. It is doubtful, however, whether the method has been applied to any extent in the foundry. In my opinion, by working under standard conditions, the founder would find it useful. A modified method has been described by Dr Rogers for the investigation of fractures.[1]

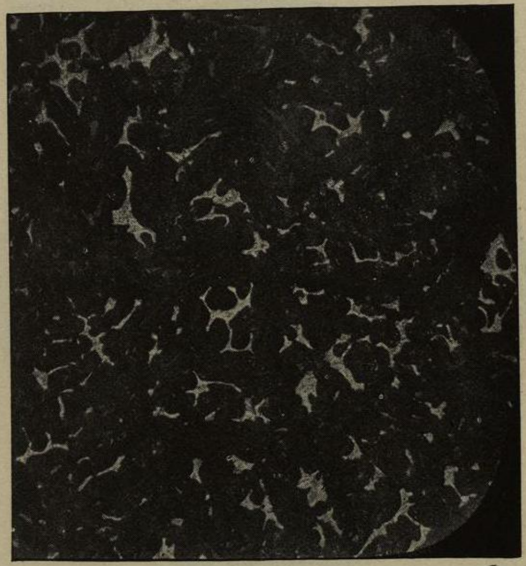

Fig. 117.—Phosphide of iron eutectic in pig-iron containing 0·7 per cent. phosphorus.

Phosphorus in Pig-Iron.—As practically the whole of the phosphorus in grey pig-iron segregates as phosphide of iron eutectic, and is distributed in minute isolated masses throughout the pig-iron, it is evident that the total volume of these isolations in a given mass of the pig-iron must have some close relation to the proportion of phosphorus present.

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[1] *Jour. of I. and S. Inst.*, No. 1, p. 385 (1912).

Phosphide of iron is not acted upon by dilute acids, whereas the inter-metallic portions between the phosphide and the graphite are readily dissolved and darkened. If a small piece of the metal be polished brightly on very fine emery paper and then dipped in dilute nitric acid, the greater part of the mass will be darkened, but the minute masses of the phosphide will remain bright. With pig-irons rich in phosphorus these areas can readily be seen without any magnification, but if the amount be small they can only be detected by the microscope. By comparing polished and etched specimens of pig-iron we can readily find out which iron is rich and which is poor in phosphorus.

Fig. 118.—Phosphide of iron eutectic in pig-iron containing 0·3 per cent. phosphorus.

Experience has shown that it is easy, after a little

practice, to classify pig-irons with 0·01 per cent. to 0·10 per cent. of phosphorus into their relative order, and a founder who is making castings, such as ingot moulds, may find by examination of a small chip of the metal whether the phosphorus is, say, 0·05 per cent. or 0·10 per cent., and, by comparing it with chips cut from the pig-iron melted, whether the phosphorus has increased by the accidental introduction of impurity.

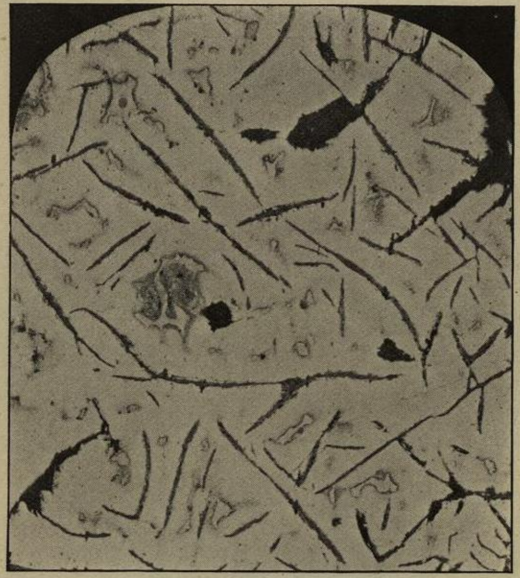

Fig. 119.—Pig-iron containing 0·045 per cent. combined carbon.

Black lines = graphite.
Half tone = pearlite.
White = silico-ferrite.

In the higher percentages of phosphorus, it is easy to tell whether there is 0·5 per cent., 1·00 per cent., or about 1·5 per cent. (figs. 116–118).

Of course it must be understood that the microscope cannot take the place of chemical analysis, and that the interpretation of what is seen through the microscope must necessarily be considered as only approximate.

Combined Carbon in Pig-Iron.—Next in importance to the fracture of pig-iron comes the proportion of combined carbon. As is very well known, the amount of pearlite in slowly cooled steel, as seen under the microscope, is proportional to the combined carbon present, and the more combined carbon and pearlite there is in pig-iron the harder will be the iron—other things remaining constant.

Fig. 120.—Pig-iron containing 0·4 per cent. combined carbon.

Black lines = graphite.
Half tone = pearlite.
White ground mass = silico-ferrite.

If the carbon as carbide be low, the iron will machine easily; if high, it will be more suitable for cylinders, and will be more difficult to machine.

As a rule, if the combined carbon be low the iron will bear being mixed and melted with more old scrap and steel than is the case with metal richer in carbon in that state. An iron of No. 1, 2, 3, or 4 fracture, if free from combined carbon, is, as a rule, rich in silicon (figs. 119–121).

Fig. 121.—Pig-iron containing 0·8 per cent. combined carbon. Ground mass is pearlite The white patches are iron phosphorus eutectic. Note that the half-tone portions representing pearlite are proportional to the combined carbon. In fig. 119 it is very little, in fig. 120 it is greater, while in fig. 121 all the ground mass is pearlite. Ferrite decreases as the pearlite increases, and the ferrite develops in the direction from graphite to the phosphorus eutectic.

In polished sections of pig-iron etched with a 5 per cent. solution of picric acid in alcohol, or with other suitable reagents, it can readily be discerned what the approximate amount of combined carbon is by the proportion of pearlite present.

Usually in pig-irons in which the whole intermediate mass is pearlite, the combined carbon is about 0·75 per cent., but this varies with the content of phosphorus, and possibly with other constituents.

Fig. 122.—Malleable casting, showing broad ferrite envelope. × 50.

The above remarks, therefore, only apply to pig-iron of the normal size, cast in sand or other non-conducting medium.

Malleable Cast-Iron.—There are two classes of malleable cast-iron, the black heart and the ordinary which has a white fracture. The ductility of the former is the result mainly of a change in the carbon condition from carbide carbon to annealing graphite—usually called temper graphite,—whilst that of the latter is due to a partial removal of the carbon from the metal by oxidising agents. It is in the examination of the latter, or the decarburised material, that the microscope is useful. By its use one can tell the extent to which the carbon has been removed, and whether the surface layers have become recarburised and the bending properties of the material coincidentally reduced, a result sometimes experienced (figs. 122 and 123).

Fig. 123.—Malleable casting, showing evidence of recarburisation on the outside layer which made the casting weak. × 50.