pearlite, whatever the temperature of annealing may be, only, the higher this temperature has been, the more the isolated parts tend to develop.

The best means of determining by metallography the temperature to which this class of steels have been heated, or the end temperature of forging, is to etch, after plain polishing, by immersion in nitric acid at 36° Baumé. The attack is limited by the passivity of the iron: it would, however, be too strong if it were a question of studying the details of the pearlite. But, for exactly the same reason, it furnishes in an oblique light, under the small enlargement of about 50 diameters, a wavy appearance which is more developed in proportion as the temperature sought has been high.

C. Influence of Quenching.—A disc was heated and quenched at 735° in water at 15°. Hardening at this temperature produces fractures.[1] Three fissures visible to the naked eye start from a common point near the centre, and lead towards the edge without reaching it. These fissures are broken, like those of fig. 157, and are often divided into isolated regular polyhedrons. Polishing on rouged parchment leaves in relief strips harder than quenched steel, and these remain bright after a 5-seconds' attack by 20 per cent. nitric acid. These are the remains of cementite.

As for martensite, which is in this case hardenite,[2]

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[1] The whole secret of hardening without cracking appears to be in quenching before the end of the transformations (during the heating) or after their finish (during the cooling). But that is easier said than done when the eye is the only guide. Hence the necessity for specialists. Again, these specialists are often found in error, when the point to which they have been accustomed is changed. Then they declare that the new steel is bad.

[2] See concluding paragraph on p. 237.

it keeps its usual forms and shows them by known characteristics; but the needles are smaller and less distinct than those we have previously found (fig. 167: polish-attack: V × 1000).

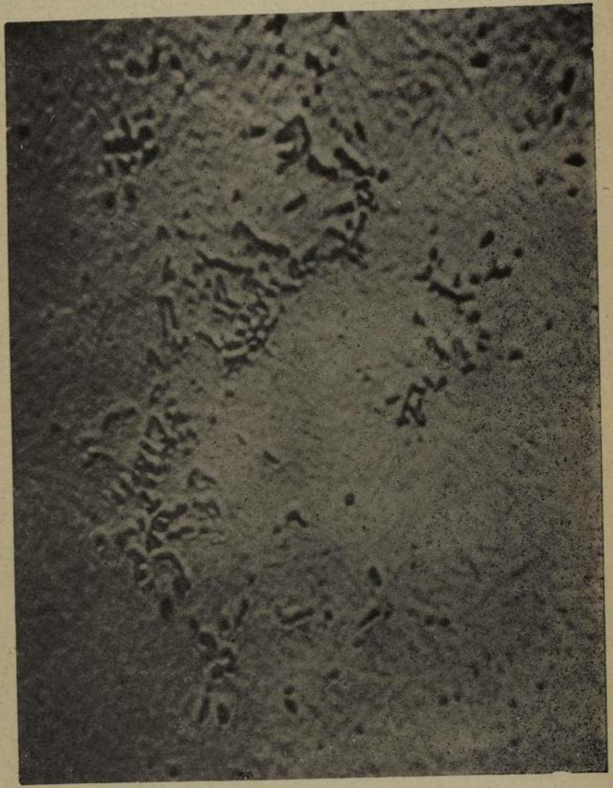

Fig. 167.—CARBON 1·25 per cent. Reheated to 735° C., and quenched in water at 15° C. Polish-attack. V × 1000 diameters.

The cementite which has separated a little above the critical point is dark in the photograph. The presence of this cementite about the point Ac_1 is an interesting fact which will be useful in drawing conclusions.

If the quenching be done towards 1050° or above, cementite is absent, and austenite appears (fig. 168: V × 250). On this photographic preparation, which in reality is from another slightly different steel, the structure has been developed by polish-attack. The austenite was slightly in intaglio, and the photograph, taken a little below the mean focussing point, shows it black while the hardenite is light. It will be seen that this last form of barbed needles, whose axes are often parallel to two or three directions, predominate on a given grain.

Fig. 168.—Carbon 1·25 per cent. Quenched from 1050° C. Polish-attack. V × 250 diameters.

Quenching during recalescence, in water at 15° C., gives a mixture of isolated transformed grains, and grains not transformed, with others of intermediate character. Those not transformed are naturally hardenite with a surplus of independent cementite; those completely transformed before the quenching took place are pearlite. The hardenite is surrounded by troostite, the pearlite by sorbite, and the passage from troostite to sorbite takes place very gradually.

V.—STEEL WITH 1·57 PER CENT. CARBON.

A. The Natural Cemented Metal.—The description of this has been given previously (pp. 175 and 176), accompanied by figs. 125 and 126.

B. Influence of Quenching—

(a) Negative Quenching.

The cementation finished, a few bars 12 or 13 mms. in diameter were drawn from the cementation furnace at maximum temperature and cooled in the air. For bars of this dimension and hardness, cooling in the air can be considered a negative quenching. The microstructure (fig. 169: polish-attack: V × 1000) shows the plates of white cementite in parallel groups, and the remainder is sorbite beginning to separate into pearlite.

(b) Positive Quenching.

On heating and quenching at a temperature higher than $Ac_{3 \cdot 2 \cdot 1}$ and lower than about 1000°, the cementite is not completely dissolved at the time of the quenching, and is found in the principal mass of hardenite, which constitutes the quenched metal.

If the quenching be effected from a temperature of about 1050° in iced water, in a freezing mixture of snow and common salt, or in mercury cooled below zero, only traces of cementite are left, in the shape of very fine parallel barbs at the edges of the grains:

around them and attached to the same edges there may be little nuclei of troostite. All the rest—that is to say, nearly the whole of the preparation—is composed of the mixture of hardenite and austenite which has been described on pp. 188–191, and illustrated by figs. 133–135.

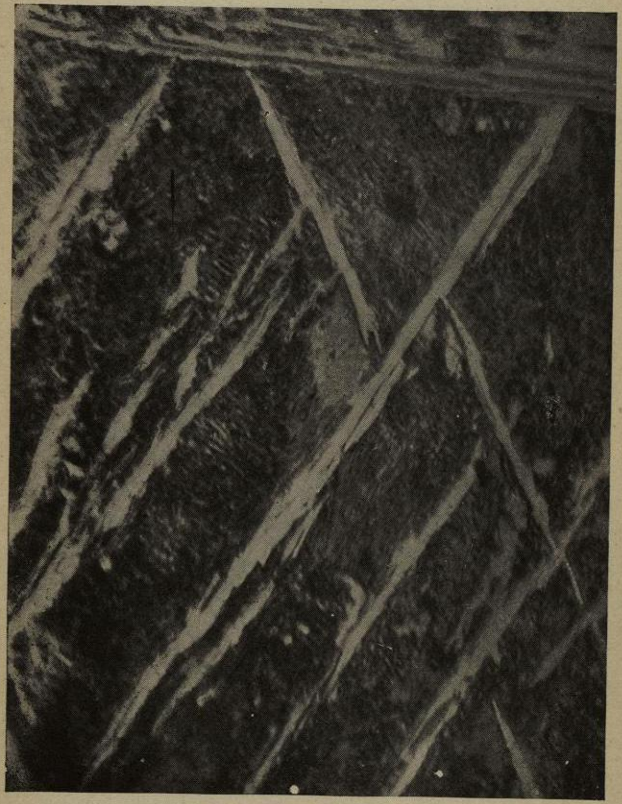

Fig. 169.—Carbon 1·57 per cent. Cemented steel drawn from a cementation furnace and cooled in air. Polish-attack. V × 1000 diameters.

The variation of the temperature of quenching between about 1050° and 1300° does not appear to have any marked influence. But if the initial temperature is above 1050°, and the disc is quenched in a bath of warm water—say at 70°—independent cementite separates, and consequently austentite is no longer present. Austenite can still be obtained by quenching in water at a temperature of 15° to 20° when using very small specimens; but the result is uncertain, the more so as oxidation is rapid at the high temperatures needed, and the decarburisation of the specimen is great. It is a much surer method for the preparation of austenite to quench, in iced water, pieces 6 to 7 mms. thick. In every case the structure must be examined on a section sufficiently below the surface if the heating has been done in an oxidising atmosphere. Thus we see that it is convenient that the crystalline structure before quenching should be as gross as possible. The best process to obtain austenite is to take the steel direct from the cementation furnace at its maximum temperature and quench it directly in iced water. In this manner, Mr Grobot, Director of the Assaily Steelworks, was good enough to prepare for me the samples which led to the discovery of austenite.

C. Influence of Tempering.—Two bars quenched in iced water from about 1050° were placed, with a Le Chatelier couple between them, in a porcelain tube enveloped in a covering of asbestos. They were placed in the muffle tube of a Mermet furnace (at a constant temperature) and then heated. The results were plotted on a chart, and indicate the successive periods necessary for the temperature to rise 1° on the pyrometer. These are given in the diagram (Plate II.). It is seen that, under the conditions of the experiment (other conditions giving different results), the rate of heating shows three accelerations. The first, towards 140°, is feeble, and therefore doubtful; the second begins towards 275°, and, increasing progressively towards 400°, reaches a very distinct maximum between 400° and 500°, and ends rapidly between 500° and 540°; the third is less pronounced, and was not reproduced in another trial. It begins towards 610°: and at about 700° we find the triple point known as $Ac_{3\cdot 2\cdot 1}$.

Knowing in this manner the main temperature of the course of tempering, four samples, previously quenched from 1050° in iced water, were tempered at increasing temperatures under the same conditions of heating, and the micro-structures were studied after tempering. The micro-structure after quenching is given in figs. 133 and 134, and described in connection with the definition of austenite.

The tempering of the first samples was stopped at 275°, the steel being of pale yellow colour—that is to say, before the commencement of any great acceleration in the recalescence. Hardenite, which before tempering could not be scratched by a sewing-needle and was not coloured by polish-attack, is now slightly scratched—less than austenite—and is browned by the polish-attack with liquorice-root. Thus figs. 133 and 134 are reproduced (pp. 188 and 189).

The tempering of the second sample was stopped at 395° at the beginning of the recalescence, the surface of the metal being blue. The former structure is slightly revealed by polishing in bas-relief. The differences of level are very feeble, but they are inverted, the austenite now being rather in relief on the hardenite: a scratch

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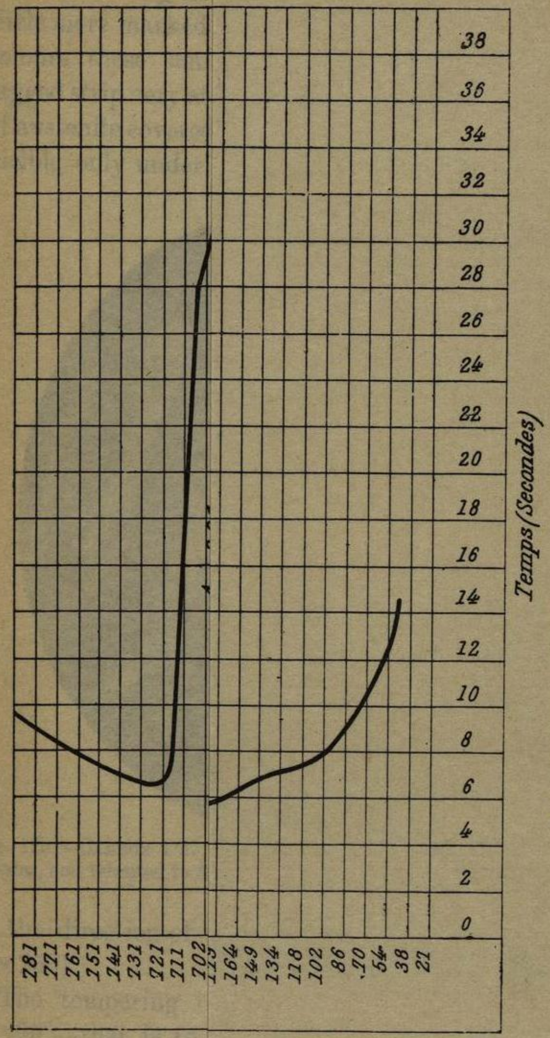

Heating Curve of Harden Steel containing 1·57 per cent. Carbon.

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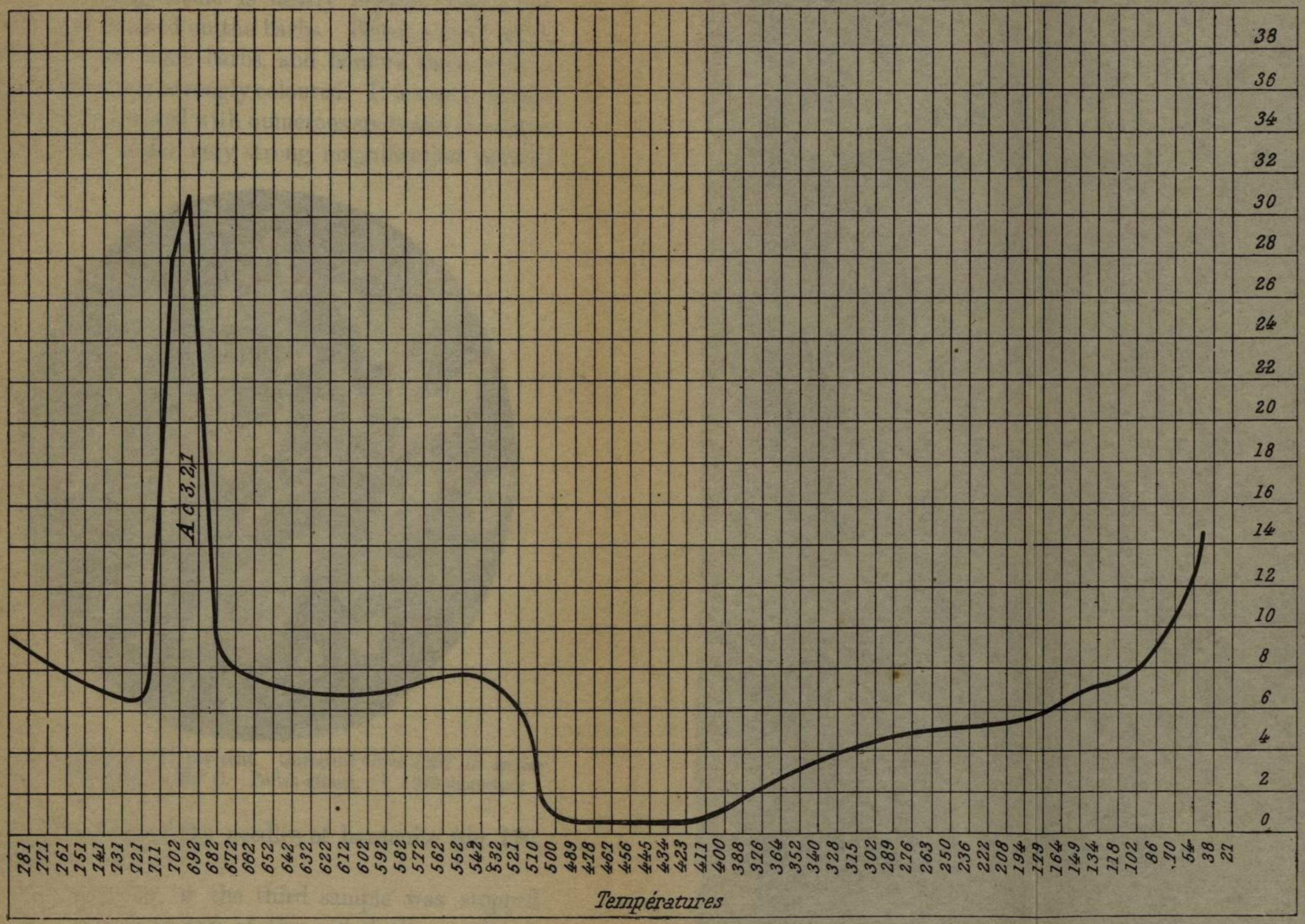

Heating Curve of Harden Steel containing 1·57 per cent. Carbon.

with a sewing-needle is nearly regular, perhaps a little more marked on the barbs. Polish-attack easily colours these same barbs, and borders them with a jagged strip very strongly coloured. It leaves a residue of austenite covered with numerous spots and cleavages visible only under very strong magnification parallel to the direction of the needles of hardenite (fig. 170, V × 250).

Fig. 170.—Carbon 1·57 per cent. Quenched from 1050° C. in ice water, and reheated to 395° C. Polish-attack. V × 250 diameters.

The tempering of the third sample was stopped at 495°—that is to say, at the end of the maximum of the recalescence. By polish-attack the primitive structure remains confusedly recognisable (fig. 171, V × 250), with the demarcations greatly diminished.

The tempering of the fourth was done at 620°. Polish-attack gives a coloration nearly homogeneous, on which the old structure can still be distinctly seen.

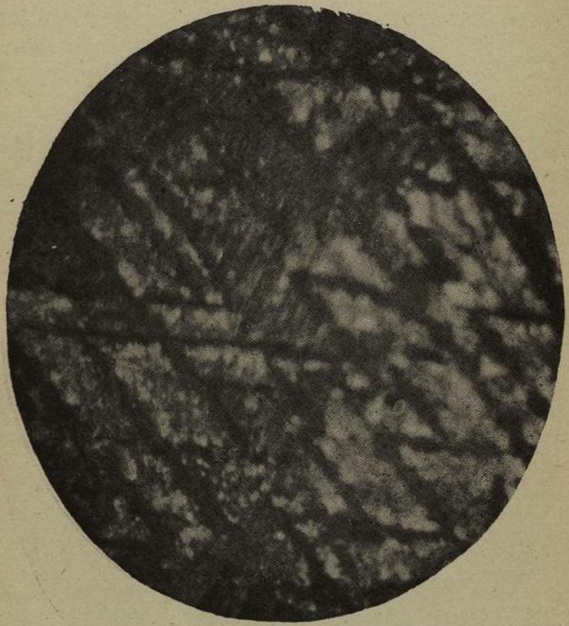

Fig. 171.—Carbon 1·57 per cent. Quenched from 1050° C. in ice water, and reheated to 495° C. Polish-attack. V × 250 diameters.

These results show that tempering progressively transforms hardenite and austenite—the first more quickly than the second—to troosite, and ultimately to sorbite.

CHAPTER VIII.

SEGREGATION IN STEEL AND THE PHENOMENA OF BURNING, OVERHEATING, AND WELDING.

It is only with the aid of the microscope that it is possible accurately to follow the changes which occur during the solidification, overheating, burning, and welding of steel.

When medium and low carbon steels containing small quantities of sulphur and phosphorus pass from the liquid to the solid state, the first portion to fall out of solution is practically pure iron, which crystallises in octahedral skeletons. When the steel cools in a mould these crystallites start to grow on the cool walls and develop inwards at right angles to the sides of the mould. The crystallites growing in this way reject much of the more fusible part of the metal and force it forward. Consequently, the outer layer, or that which freezes first, is always lower in phosphorus and sulphur than the average steel in the ingot. Many erroneous analytical results have been obtained by taking drillings from this outer layer, which frequently contains less than half the sulphur and phosphorus present on the average for the whole ingot. The carbon, no doubt, at first accompanies the