PRACTICAL PROBLEMS IN THE METALLOGRAPHY OF STEEL.

SINCE Sorby in 1864 established the all-important fact that steel must be regarded as a crystallised igneous rock, his work has been greatly expanded by the international labours of many able microscopists. Much of the work done, however, has been of academical rather than of practical interest, and busy steel works' metallurgists, appalled by the rapid growth of constituents ending in "ite," of "eutectics" and of solid solutions of carbon or carbides in unisolated allotropic modifications of iron, are already beginning to ask themselves the question, Is micrographic analysis going to be of any real use to us, and, if so, in what direction? The present article is an attempt to very briefly answer the above questions.

The theory prevalent a quarter of a century ago that steels of identical chemical composition would necessarily have the same mechanical properties has long since been discarded. But perhaps steel metallurgists have not yet fully realised the disconcerting fact that steel of excellent chemical composition, giving highly satisfactory mechanical tests, may nevertheless utterly fail in use, possibly with disastrous results. In other words, a ductile steel which bends double cold without any sign of flaw or failure may, under the influence of vibration, snap like a piece of glass, though only subjected to mechanical stresses well below its elastic limit.

In connection with the materials of construction used for high-speed engines, both land and marine, it is at the present time a problem of paramount importance for the scientific steel metallurgist to determine the cause of the sudden infidelity of steel (or wrought iron) under vibration.

Data in the writer's possession prove beyond all doubt that steel giving splendid chemical and mechanical tests may rupture under vibration possibly in a few hours or perhaps only after the lapse of twenty years.

There is little doubt that in many cases the microscope is capable of giving warning of the dangerous character of a steel, chemically, and apparently mechanically, safe. To intelligibly describe the structures of safe and dangerous steels it is necessary to consider:

(*a*) The micrographic constituents of structural steel.

(*b*) The molecular migrations of these constituents when at a red heat the metallic mass is in a semi-plastic state.

To put the case concretely, the chemical constituents of a typical rail may (in addition to iron) be approximately taken as carbon 0·40, silicon 0·05, manganese 0·90, sulphur 0·06, phosphorus 0·06 per cent., together with small percentages of arsenic and copper. The micrographic constituents of such a steel are:

(1) The pale, simple constituent ferrite (in this case somewhat impure iron).

(2) The dark etching compound constituent pearlite, consisting of mixed granules of iron and of a double carbide of iron and manganese.

(3) The dove-grey simple constituent sulphide of manganese, MnS.

It is important to remember that in manganiferous steels the foregoing constituents are only completely differentiated visually on slow cooling from a full red heat, a fact which at once introduces the vital question of the migration of constituents. Speaking broadly, it may be said that sulphide of manganese is not, under working conditions, capable of migration to any appreciable extent. Thus it remains to consider only the migrations of the ferrite and pearlite.

The movements of these constituents on heating may be termed "diffusion," and their movements on cooling "segregation."

On heating the typical steel specified to about 700° C. the compound constituent pearlite is converted, with absorption of heat, into the simple constituent, martensite, at Osmond's point A_c1. Then, passing through Osmond's points A_c2–3, the constituents ferrite and martensite diffuse one into the other till, at about 800° C., molecular equilibrium is eventually established.

If, however, the steel be cooled very slowly, the molecules of martensite and of ferrite will perfectly segregate in the respective proportions of about 45 and 55 per cent. Then at Ar. 1, about 640° C., the martensite will decompose into the compound constituent pearlite, which, owing to the presence of manganese, will be granular and not laminated. On the other hand, if the steel is somewhat quickly cooled in air, the segregation of the constituents will be imperfect and the apparent proportion of pearlite relatively large, because, owing to the influence of the manganese present, the phenomenon of constitutional segregation is retarded.

As a matter of fact, the apparently large area of dark pearlite is really an extremely intimate mixture of true pearlite and unsegregated ferrite.

The writer is aware that these statements may provoke theoretical opposition, but they nevertheless describe the observed facts, and by these, and not by theories, the practical metallurgist must be guided.

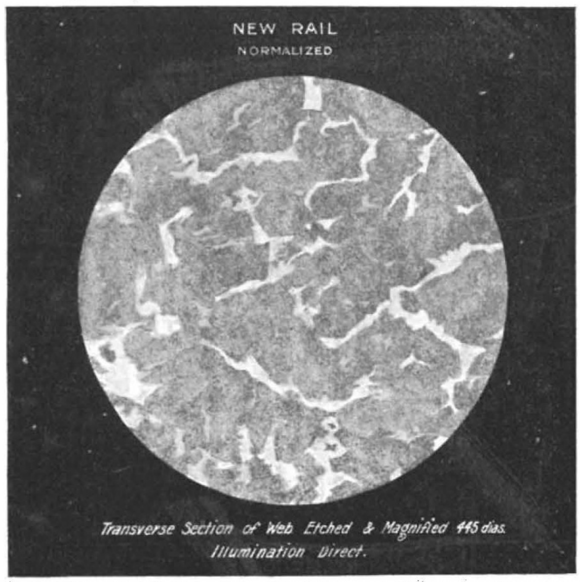

FIG. 1.—Size of original drawing, six inches; magnification, 445 diameters. The magnification here represented is about 166 diameters.

The micrograph Fig. 1 shows the transverse section of a rail web re-heated to 900° C. and allowed to cool in air; and this web exhibits the same structure in all the three planes of section presently to be referred to.

The micrograph Fig. 2 shows the structure when the rail was slowly cooled in the re-heating furnace during a period of 50 hours.

In Fig. 1 the pale ferrite has imperfectly segregated in the form of ragged and broken cell walls imperfectly environing cells of pearlite mixed with unsegregated ferrite.

In Fig. 2 the pale ferrite and dark granular pearlite have perfectly segregated mainly in the form of thick, alternating laminæ. The structure last named must be regarded as highly dangerous, because under vibration the adhesion between the constituents is liable to gradually loosen and finally to be destroyed. Nevertheless, mechanical tests would initially reveal little difference in the ductility of the two pieces of rail.

The foregoing facts give the clue to the direction in which the steel microscopist must look for danger with reference to rupture under vibration.

In a brief article it is difficult to do more than give suggestions, but it is necessary to point out that the majority of published micrographs exhibit a single plane of transverse section. Such representation can give only a very partial knowledge of what may be termed the solid geometry of steel.

To determine this it is necessary, in rolled metals, to make three micrographs in three planes of section at right-angles to each other, namely (*a*) a tranverse section, (*b*) a longitudinal horizontal section, (*c*) a longitudinal vertical section. From these the exact form in which any constituent exists in the mass can be determined.

As an example, the case of the constituent sulphide of manganese may be taken. It must be remembered that 0·09 per cent. by weight of sulphur corresponds to no less than 0·5 per cent. by volume of manganese sulphide, a very appreciable amount for a micro-constituent.

In the original ingot during solidification and cooling the sulphide segregates into roughly globular masses

FIG. 2.—Size of original drawing, six inches; magnification, 112 diameters. The magnification here represented is about 42 diameters.

On reheating the ingot for rolling, the sulphide liquefies and the liquid globules are elongated in the direction of the rolling, and necessarily to some extent in a line at right-angles to that direction. Hence in a steel plate, the sulphide may present in the three planes of section above specified the appearances exhibited in Fig. 3, which shows that the sulphide is distributed throughout the steel in the form of irregular, oval laminæ.

It will be obvious that the evil mechanical influence of this constituent will be at its minimum along the length of the plate, somewhat greater across the plate, and at its dangerous maximum through the thickness of the plate.

Perhaps an obstacle to the development of steel works' metallography, even greater than the terror inspired by an unnecessarily complicated nomenclature, is the apparatus, time, care and special reagents supposed to be necessary to obtain, by polishing and etching, a good micro-section. In the advocacy of this view no one has been more earnest than the writer, and for research purposes it is doubtless sound. But for works' purposes, in connection with most steels, it must be confessed that such necessity has been exaggerated.

The writer has, therefore, pleasure in withdrawing his former view owing to experience having proved that by a very much simplified modification of method, a micro-section may be placed upon the stage for examination in five minutes after it leaves the dead smooth file in the machine shop. This process, which entirely does away with elaborate polishing apparatus or special etching reagents, is as follows:

Take two pieces of hard wood, 12″×9″×1″, planed dead smooth on one side; then by means of liquid glue evenly attach to the smooth faces two sheets of the London Emery Works Co.'s Atlas cloth, No. 0. Allow the glue to set under strong pressure. Next, by means of a smooth piece of steel, rub off from one of the blocks as much as possible of the detachable emery. This is No. 2 block, the other, necessarily, No. 1 block.

The steel section, say $\frac{1}{8}$ inch thick and $\frac{1}{2}$ inch diameter, is rubbed for one minute on No. 1 block, the motion being straight and not circular; then, for the same time and in the same manner, rub on No. 2 block. Next place the bright but visibly scratched section in a glass etching dish 3″×1′×$\frac{1}{2}$″, and cover the steel with nitric acid, sp. gr. 1·20.

Watch closely, until in a few seconds the evolved gases adhering to the section change from pale to deep brown and effervescence ensues. Then, under the tap, quickly wash away the acid and for a minute immerse

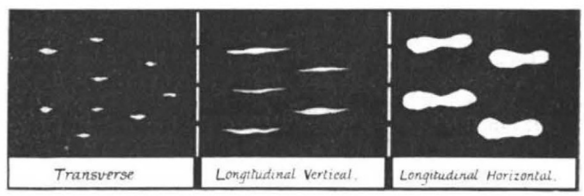

FIG. 3.

the piece in a second dish containing rectified methylated spirits. Dry the section by pressing it several times on a soft folded linen handkerchief, when it will be ready for examination. The structure will be clearly exhibited, the innumerable fine scratches visible before etching having virtually vanished.

The micrographs illustrating this article were prepared in a very few minutes by the above process, and have been accurately reproduced by Mr. F. Ibbotson. The writer hopes that this simple and rapid method may help to stimulate in steel works' practice a more extensive study of metallography.

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THE WORK OF THE REICHSANSTALT.

A THICK quarto volume of nearly five hundred pages[1] gives a full account of the recent scientific researches of the Reichsanstalt. It is impossible, and perhaps not very useful, to attempt in the brief compass of a notice any full description of these varied investigations. All who are interested in physical measurement know that when a paper on any subject is issued from the Reichsanstalt it must be studied by any workers who come after.

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The volume opens with Dr. Thiessen's research on the

1 Wissenschaftliche Abhandlungen der Physikalisch Technischen Reichsanstalt. Band iii. Pp. 477. (Berlin: J. Springer, 1900).