Colour Metallography of Ferrous Alloys and its Applications to Iron and Steel Making

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REAGENTS used to show the structure of metallographic samples may give reaction products which dissolve in the reagent ; or, on the contrary , products may be insoluble and remain in the place, forming thin films, more or less adherent.

Both kinds of reagents attack the various constituents, at least in the initial stage, at different rates ; namely, they are selective with respect to :

1. The different phases in the sample.
2. Heterogeneity of solid solutions.
3. Crystallographic orientation of the phases.
4. Internal stress in the lattices.

In boundaries between crystal grains of a metal aggregate, these different heterogeneities accumulate in large measure, and, therefore, boundaries are generally etched by reagents more quickly than the core of the grains, consequently, reagents of the first kind, at the first steps of attack, develop on the surface of the sample a network of grooves, more or less deep, which shows the granular pattern of the aggregate.

Therefore, the surface of the sample, which was mirrorlike before etching, becomes uneven and, at the microscope, through the contrast of lights and shadows, reveals the structure of the metal.

With the second kind of reagents, on the other hand, the products of reaction form, at least in the first steps of attack, films which are more or less epitassic, and whose thickness is a function of etching rate, and, therefore, of the above mentioned heterogeneities.

When etching goes on for a longer time, the first layers formed protect to some extent the underlaying metal, and the rate of subsequent etching is influenced also by other factors, as for instance, diffusion rate of the reagent through the first layers formed.

Polishing and etching of the samples

We use mainly the classical electrolytic polishing method of Jacquet.

However, this method is not suitable for cast iron, since graphite is removed and the small cavities so resulting are corroded irregularly at their edges.

Therefore, mechanical polishing is used, alternating it with etching by dissolving reagents of the first

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kind, in order to remove the work-hardened layer. Polishing such samples is often a very laborious operation, and may involve as many as 20 to 30 times etching and polishing.

After polishing, sample is first etched with a reagent of the first kind, in order to reveal structure and to remove any residual of deformed layer.

The sample, carefully washed and dried, is then oxidised in air, by putting it on a heated metal plate, and watching its colour variation. When the desired average colour is reached, the sample is briskly cooled by immerging its lower part, which was in contact with the hot plate, into mercury.

Temperatures used for oxidation in air are about 250°C for carbon steels, alloy steels and cast irons, and about 500°C for stainless steels.

Time of attack in air is a few minutes, and generally does not exceed 15 minutes.

Preserved in a desiccator, oxidised sample surfaces keep for a long time.

Interpretation of structures

Since early examinations, we realised that a systematic research was needed to recognise the influence of alloying elements, alterations corresponding to topographic displacements of phases and heterogeneity of solid solution, effects of hot and cold working and heat treatment.

Therefore, thousands of samples were prepared and observed, and a documentation which now exceeds 2,000 colour micrographs was gathered. These include : white and grey cast irons, with lamellar and nodular graphites malleable cast irons, a wide range of carbon steels, austenitic stainless steels, manganese steels. Steels have been examined as cast, forged, rolled, drawn. Welds, as well as case hardened samples, were also examined.

A broad explorative work has been made on a mild steel, cold drawn with increasing deformations ; these samples have been tempered at increasing temperatures and for increasing times, observing the recrystallisation process step by step.

A very large documentation has been gathered on irons, steels and austentic stainless steel in the as-cast condition.

In austentic stainless steels, formation of etching figures and twinning were specially studied.

Further, for stainless steels, a great number of colour micrographs have been made showing hetero-

geneity of solid solution, and modifications resulting from plastic deformation and heat treatment.

The most recent work developed concerns the influence of very small impurities on structure of cast iron. Influence of arsenic, lead, antimony and tin has been taken into consideration and evident correlations have been shown between impurities content, distribution and strength of graphite, and aspect of structure.

Most interesting observations have been made on these iron samples after a malleablizing treatment, and the influence of impurities on the tendency to ferritize has been stated.

We have selected a set of micrographs, for each of which we have prepared a description, in order to show the most interesting metallographical aspects and give a general view of possible applications of this method.

Summary description of some applications

(a) *Mild steel, as cast.* Gathering of ferrite grains of similar orientation into colonies (or groups) is evident. Many coloured and variously shaped ferrite grains ; pearlite scattered in small islands or crossing formation, prevailingly with Widemanstatten structures. Often the elongated pearlite formations limit differently coloured areas (colonies of ferrite grains similarly oriented. Differently coloured areas limited by pearlite formations. Example of leaf-like structure.

(b) *Mild steel, as cast.* Large ferrite and pearlite grains may be seen. In the former, colour shades may be observed, which for their position in respect of inclusions set in lines, are evidently correlated to the position of primary boundaries and corresponding segregation. Ring of segregation developed independently of alpha boundaries. As the above.

(c) *Mild steel, cold-drawn* (with different degrees of deformation, up to about 90%). A sensible grouping of elongated grains into two types of colour is noted which evidently correspond to re-orientation of grains.

(d) *Ferrite after deformation and complete recrystallization in a homogeneous phase.* Random distribution of orientation of ferrite grains, that is materially different from that observed in samples in as-cast condition.

(e) *18-8 stainless steel, as cast.* Prevailing influence of dendritic segregations can be noticed. Zones with different general tonality in relation to different orientation are also noted.

(f) *Samples of stainless steel,* as cast, at increasing magnifications. Relations between dendritic hetereogeneity and austenitic grain boundaries can be perfectly observed ; each grain shows a particular range of tonalities, function of orientation as well as of segregation. With higher magnifications it can be observed that a boundary is in a position entirely different from that corresponding to primary segregation.

(g) *Stainless steel, hot worked* (at a comparatively low temperature). Orientation of structural elements of primary segregation can be seen, while grain structure is visible. Detail of cold deformation. The influence of segregations on colour is still evident. General aspect of forging structure.

(h) *Stainless steel, strongly cold worked* through rolling, then heated to 1,200°C and quenched in water.
Recrystallisation is complete and, in this case, influence of crystal orientation is small. In grains, many twins can be observed ; general trend of primary heterogeneity bands, parallel to lines of slags, shows direction of deformation.

(i) *Annealed forging.* Colour still shows a banded segregation.

(j) *Stainless steel, as cast.* Evident correlation between primary segregation and carbides. Colour transition within large austenite grains takes the form of dotting more or less rarefied.

(k) *Stainless steel, rolled and hardened.* Relation between the numerous attack figures and grains of different colours is observed.

(l) *Manganese steel, at cast.* Dendritic segregation with different colour tonalities in different austenitic grains. As in austenitic stainless steels in the as-cast condition, influence of orientation and of segregation is observed.

(m) *Manganese steel, as cast, treated.* Traces of dendritic hetereogeneity can still be seen.

(n) *Austenitic cast iron*, treated to spheroidize graphite. Matrix is quite similar to that of stainless steels ; dendritic segregation is evident.

(o) *Gray iron,* with a prevailing pearlitic matrix. Often graphite lamellae separate grain colonies (or groups) of similar colour tonality ; the same at stronger magnification.

(p) *Lamellar cast iron, annealed.* The influence of segregation is still evident.

(q) *Ferritized cast iron, with lamellar graphite.* Colonies (or groups) of ferrite grains with similar orientation can be seen, but no more relation exists with graphite lamellae. Influence of primary segregation is evident. Little colour differences among ferrite grains due to their different orientation.

(r) *Lamellar cast iron, annealed.* The separation of two differently coloured areas by graphite lamellae is still evident after heat treatment.

(s) *Malleable cast iron.* Graphite has taken its usual crabs shape ; ferritic matrix has the aspect of grains uniform in size, with random orientation.

(t) *Nodular cast iron.* Note ferrite haloes with sensibly radial grains, and joints with various orientations. Graphite spheroids are surrounded by ferrite haloes, formed by almost equally coloured grains. Haloes are surrounded