# CHAPTER VI.

## METALLOGRAPHY.

**Definition.**—In the widest sense, metallography deals with the composition, constitution, structure, and physical properties of metals and alloys, but is sometimes confined merely to the microscopic examination of these materials, and in this case should be termed microscopic metallography.

**History of Microscopic Metallography.**—In metallurgy, the microscope was first applied to the examination of iron, and the first records go back to 1722, when Réaumur described the structure of a chilled casting under the microscope, and traced the changes of softened cast iron as modified by the elimination of impurities. François, again, so early as 1832, took the interesting case of the direct reduction of iron from its ores, and followed the successive changes by the aid of the microscope. The following passage, translated from this quaint and accurate observer, is full of interest, and might almost have been written by a modern metallurgist:—

"If to these analytical data observations under the microscope with a magnification of 300 to 400 diameters be added, it is seen that ordinary iron is merely a metallic network with a close-grained tissue, with submerged scoriaceous opaline, sometimes subcrystalline, portions, and with little globules and metallic grains ranged in every direction. Sometimes nests of translucent prismatic and bacillary crystals, with metallic portions adhering, are noticed hidden in the paste. These are the grains of steel which can be made to disappear by heating."

It appears that modern microscopic metallography has been developed from the study of meteoric irons, and, as has often happened in the history of science, it appears to have had several independent origins.

The publications of Dr Sorby go back to 1864, and those of Prof. Martens to 1878, but in spite of this difference in date, the labours of the latter present all the characters of complete originality. While Dr Sorby devoted himself to the







development of a complete method of examining sections of opaque bodies under the highest magnifying powers, and the application of this method to different products of the metallurgy of iron, Prof. Martens first studied, though without neglecting the examinations of sections, the general laws of fractures, fissures, blowholes, and crystallisation in metals. After 1878 the study was carried on, on the Continent and in America, by Osmond, Werth, Wedding, Behrens, Howe, Charpy, and Sauveur, but very little attention was paid to it in this country until about 1890, when Prof. Arnold commenced, and was closely followed by Stead, both of whom published papers before the Iron and Steel Institute in 1894. Since this latter date great strides have been made in this subject, and many metallurgists have devoted much time and thought to the practical and theoretical sides of the science.

At the present time it is not uncommon for metallurgical works and laboratories to be equipped with a complete micrographic and pyrometric plant in addition to ordinary chemical and testing laboratories. As has already been shown, metallic alloys occupy an important place in the industrial world; the character of some of their physical properties (hardness, malleability, fusibility, etc.) cause them to be preferred to pure metals for many purposes; yet, in spite of this extended use, very little was known about their constitution until quite recently. Each improvement introduced was the result of numerous experiments, and not of organised scientific research. Now all this is being altered, and in modern metallography we have the results of systematic research work carried out on metals and alloys by the above-mentioned metallurgists and others.

The chief point proved by these researches is that all the properties of alloys, and therefore their industrial value, depend directly upon two factors:—

1. Their chemical constitution, that is to say, the relative proportions of (*a*) the component metals, (*b*) the chemical compounds formed by these metals, (*c*) the isomorphous mixtures, or (*d*) the various allotropic modifications of the constituents.

2. Their physical constitution or structure, that is, the shape and dimensions of the crystals of the elementary constituents, which, by their juxtaposition, constitute the metallic mass.

The first aim of a systematic study of alloys must be to ascertain their chemical constitution and structure, and its final aim must be the study of the relation existing between these ascertained factors and their useful properties.

No one of the methods of research hitherto devised is sufficient to solve the problem of the constitution of alloys, and it is necessary to use all the methods by which useful information may be obtained.

The most important methods used are the following:—

1. Chemical methods.—General analysis and separation of constituents.
2. Microscopic methods.—Examination of constitutional and crystalline structure.
3. Thermal methods.—Determination of freezing-points and other thermal changes.
4. Mechanical methods.—Determination of elasticity, tenacity, ductility, resistance to crushing, etc.
5. Electrical methods.—Determination of electrical resistance and electro-motive force.
6. Magnetic methods.—Examination of the various magnetic properties.

Of these methods, the first three are used in conjunction with one another for the preparation of equilibrium diagrams, whilst all are used for the investigation of the useful properties of the alloys.

## Microscopic Metallography.

The following are the chief points ascertainable by the use of the microscope in the examination of metals and alloys:—

*a.* The crystalline state of the material, and changes in the general structure due to varying mechanical or thermal treatment. This is well illustrated by figs. 88 to 93, which show the effect of hard drawing and annealing at different temperatures on brass, the composition of which is Cu 70, Zn 30 per cent. Figs. 94 to 97 also illustrate the difference in structure of an alloy Cu 90 Al 10, when cast in sand, cast in chill, forged and annealed.

*b.* The constitution of the material, that is to say, the differentiation of the various constituents of which the alloys are built up; this is one of the most important points connected with the study of alloys. This is illustrated in fig. 98, which is a photo-micrograph of an alloy containing tin 83, antimony 11, and copper 6 per cent. The cubic crystals seen consist probably of the compound **SnSb**, while the ragged crystals running through these consist of the compound $SnCu_3$; these two sets of crystals are contained in a groundmass of eutectic. Fig. 99 shows the constitution of cemented steel slowly cooled down; the white lines consist of cementite, the carbide of iron, $Fe_3C$, while the darker groundmass consists of pearlite which, under a high magnification, would be seen to consist of alternate curved plates of cementite and ferrite.

*c.* The presence of foreign bodies, such as slag patches, is illustrated by fig. 100, which shows a number of patches of slag in a low carbon steel. Manganese sulphide in steel, oxides in steels and copper, etc., may also be detected by the microscope.

*d.* Mechanical defects, such as flaws, blowholes, and cracks,



MICRO-STRUCTURE OF BRASS.

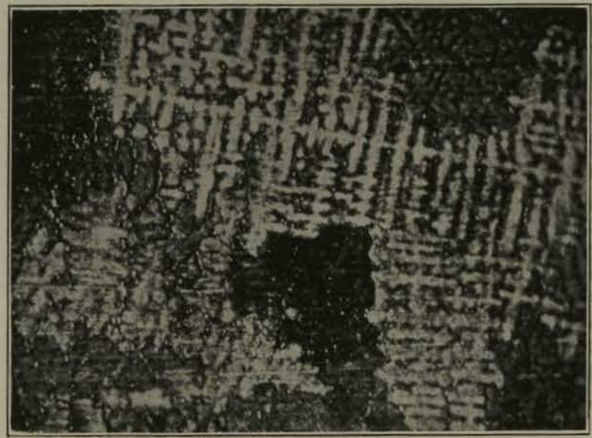

FIG. 88.—As Cast. × 50 d.

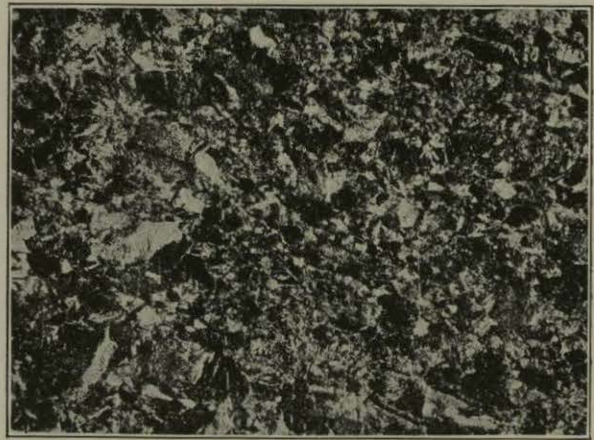

FIG. 89.—Hard Rolled. × 50 d.

MICRO-STRUCTURE OF BRASS.

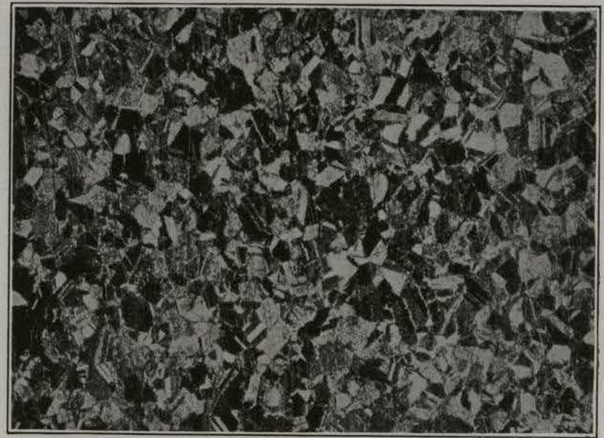

FIG. 90.—Annealed at 600° C. × 50 d.

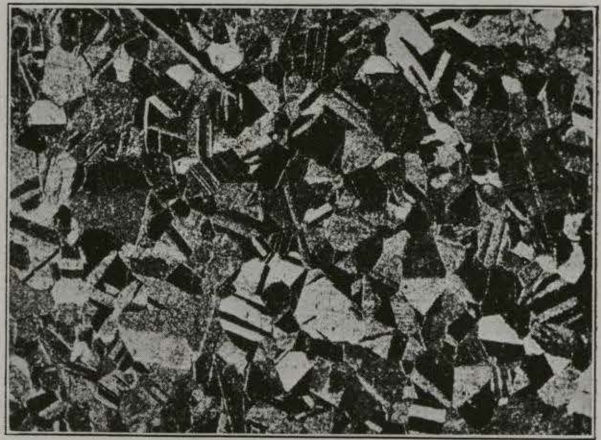

FIG 91.—Annealed at 700° C. × 50 d.

MICRO-STRUCTURE OF BRASS.

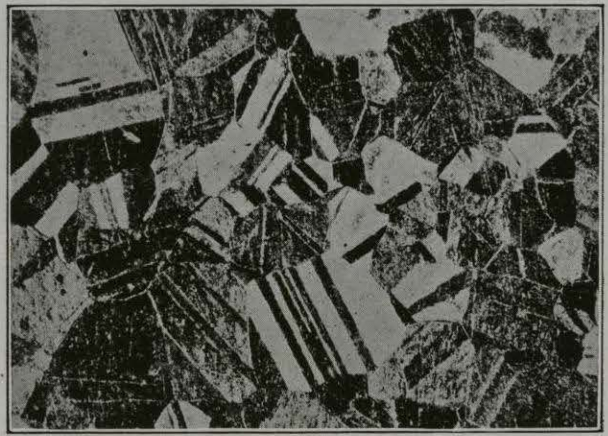

FIG. 92.—Annealed at 800° C.   × 50 d.

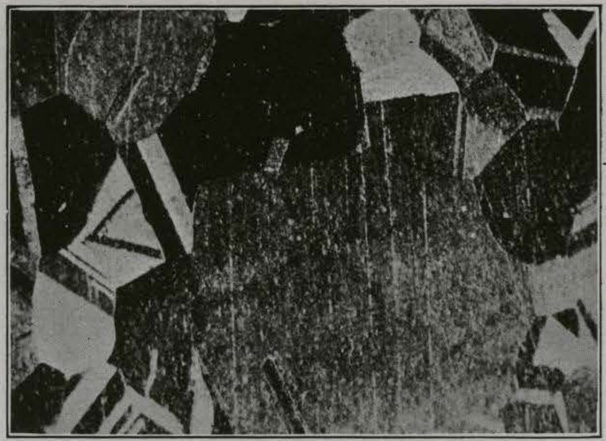

FIG. 93.—Annealed at 900° C.   × 50 d.

MICRO-STRUCTURE OF ALUMINIUM BRONZE.

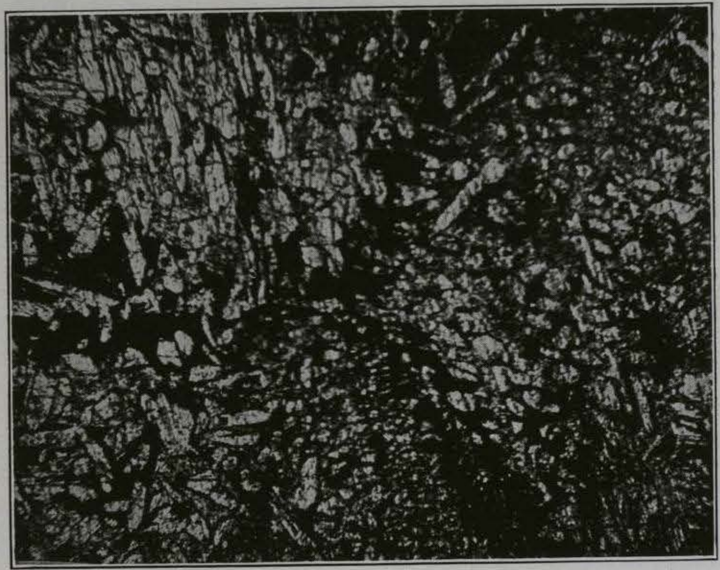

FIG. 94.—Cast in Sand. × 100 d

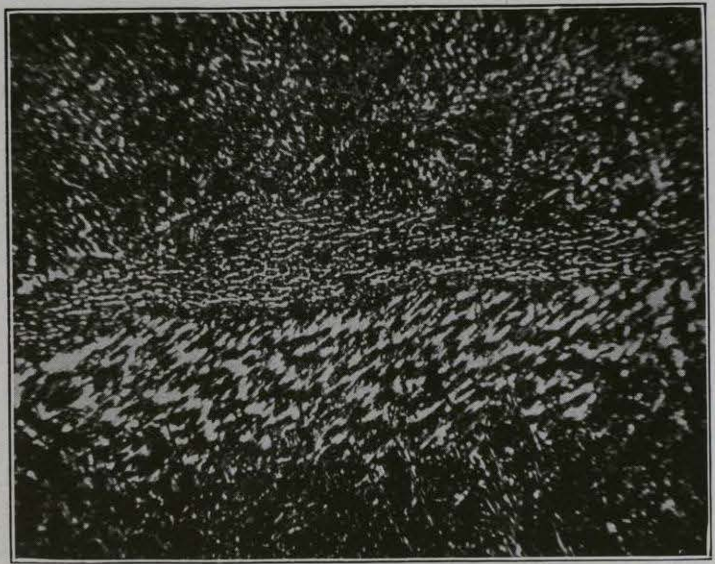

FIG. 95.—Cast in Chill. × 100 d.

MICRO-STRUCTURE OF ALUMINIUM BRONZE.

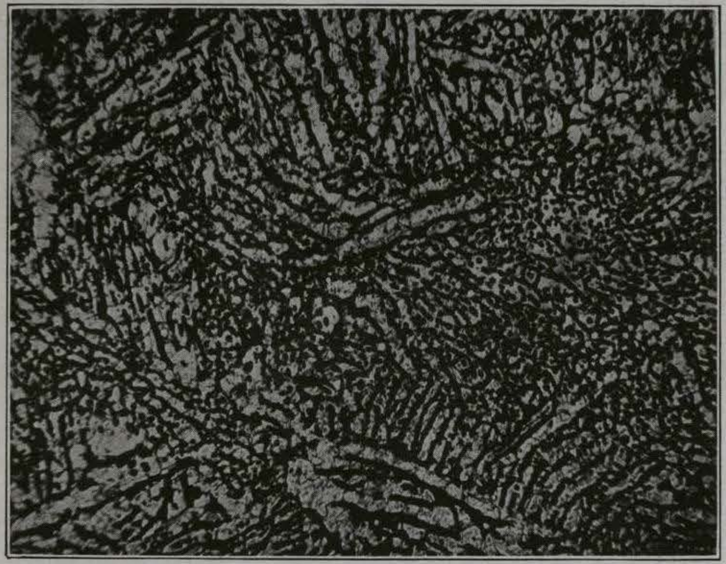

FIG. 96.—Forged. × 100 d.

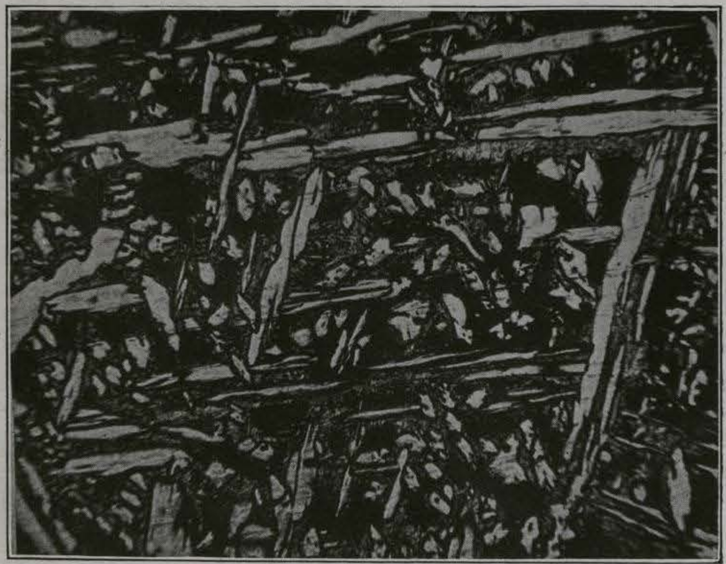

FIG. 97.—Annealed. × 100 d.

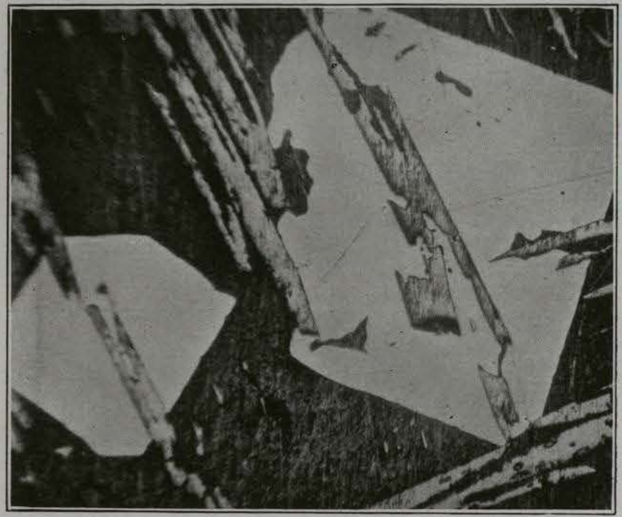

FIG. 98.—Sn-Sb-Cu Alloy. × 100 d.

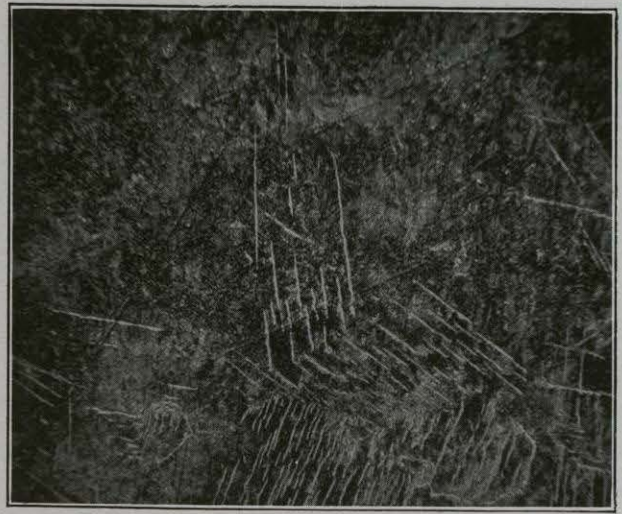

FIG. 99.—Cemented Carbon Steel. × 100 d.

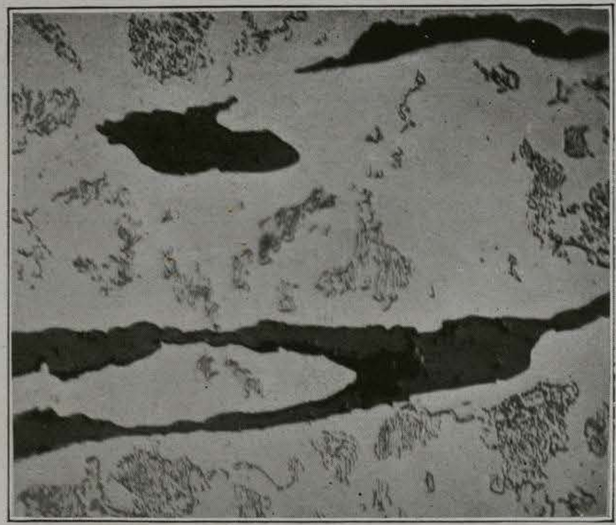

FIG. 100.—Slag Patches in Steel. × 1000 d.

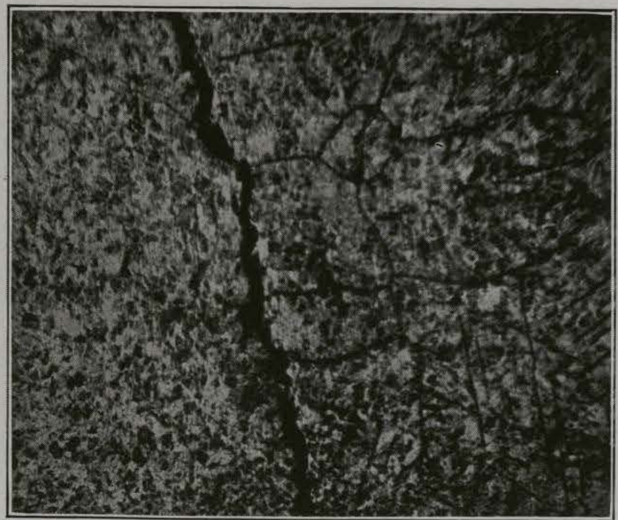

FIG. 101.—Quenching Crack in Steel. × 100 d.

FIG. 102.—Crystals of Ferrite.

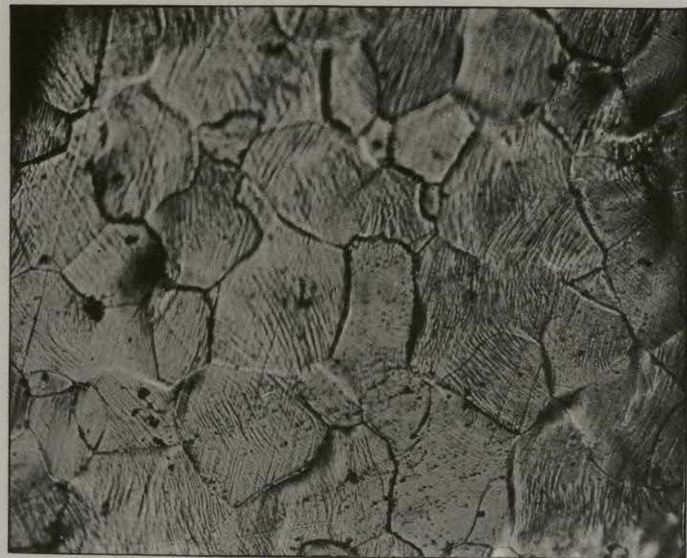

FIG. 103.—Slip-Bands in Ferrite Crystals.

the latter being illustrated in fig. 101, which shows a quenching crack in high carbon steel.

*e*. The detection of small quantities of impurities in metals which form eutectics around the grains of metal.

*f*. The effect of various stresses on structure, as illustrated in figs. 102 and 103, which show the formation of slip-bands in a piece of sheet iron, the bands having been formed by tensile deformation. These two photo-micrographs are taken from Mr Rosenhain's [1] paper on "Deformation and Fracture in Iron and Steel."

**Preparation of Photo-micrographs of Metals and Alloys.**—In order to obtain a successful photo-micrograph of a piece of metal or alloy, great care has to be taken in the preparation of the specimen by polishing and etching or otherwise developing the structure. In cases where large pieces are submitted for examination and report, such as steel rails, etc., it is well to polish a large section, etch this, and examine by means of a good lens or low-power microscope, in order to discover the portion most likely to yield useful results on thorough examination; in this manner the seat of the trouble is often quickly located. When it is decided which portion is to be examined, this is cut out by means of a hack saw, either a hand saw or an automatic power-driven saw being used. In the case of very hard specimens it is often necessary to break off a small portion by means of a sledge hammer, and to grind down the faces on an emery-wheel. In the case of very soft metals and alloys which are most difficult to polish, they are often cast on sheets of glass or mica, precautions being taken to prevent the formation of blowholes, the smooth surfaces thus obtained being suitably etched and then examined. In all cases it is far easier to get a good polish on hard than on soft materials. In ordinary cases, after cutting off the specimen, it is best to smooth the surfaces with files and roughly polish on emery cloth.

After this preparation, the polishing may be continued by one of several methods; for example, by the use of graded French emery papers mounted on revolving discs, the most usual grades being numbered respectively 0, 00, 000, and 0000; several types of electrically-driven machines have been devised for this purpose, and the papers are either attached to wooden discs by means of drawing-pins or mounted on iron discs by means of some adhesive such as seccotine.

Prof. H. Le Chatelier has devised a method of polishing by means of classified alumina powders, the details for the preparation of which are as follows:—Ammonium alum is calcined for a considerable time in a muffle in order to obtain alumina, and this is crushed and classified into a series of powders of varying degrees of fineness by means of a washing process.

The alumina is first treated with a 0·1 per cent. solution of nitric

[1] *Journ. Iron and Steel Inst.*, 1906, No. 2, p. 189.