REFRACTORY MATERIALS.

A GENERAL DISCUSSION.

At the meeting of the Faraday Society held on Wednesday November 8, 1916, at the Institution of Electrical Engineers, Victoria Embankment, London, W.C., a **General Discussion on Refractory Materials** took place. **Sir Robert Hadfield, F.R.S., President**, was in the chair.

INTRODUCTORY ADDRESS ON "REFRACTORY MATERIALS."

BY SIR ROBERT HADFIELD, F.R.S.

The Proceedings were opened by the **Chairman**, who delivered the following Introductory Address.

Introduction.—Notwithstanding the fact that the satisfactory working of steel-making and other furnaces, as well as metallurgical operations generally, largely depends upon the correct kind of refractories employed, this important subject has not altogether received in this country the attention it should have done.

A search in the Proceedings of one of the leading Metallurgical Societies shows there have been practically but few papers contributed on the subject, which is really conspicuous by its absence.

There are, I believe, about 200 makers of refractories in Great Britain, comprising about 140 in England, 40 in Scotland, and 30 in Wales; also about 12 makers of crucibles. The sources of raw products in this country are chiefly :—

- (a) Derbyshire district.
- (b) Durham and Northumberland.
- (c) Lancashire.
- (d) North Worcestershire.
- (e) South Staffordshire.
- (f) Scotland.
- (g) South Wales.
- (h) Yorkshire (including Sheffield and Leeds).
- (i) Ireland (Alumina, Bauxite, and other products).

Dr. W. Rosenhain, F.R.S., of the National Physical Laboratory, has recently pointed out that the question of refractories is of vital importance to the nation in quite a number of industries. He also mentioned

that it was more than a coincidence that several industries which had flourished, particularly in Germany of recent years, were industries which required particular attention should be paid to the character of refractories. It is evident, therefore, we in this country should more closely go into this important subject. Dr. Rosenhain's recent able work and contributions to the Society of Arts with regard to optical glass are well known, and he is also following this up at the National Physical Laboratory by researches to find the best refractories for use in ferrous and non-ferrous metallurgy, the former naturally being the more difficult problem in view of the much higher temperatures employed, up to $1,600^{\circ}$ C. or even higher, especially as electric furnaces are coming more into general use.

Professor Turner, in a recent discussion before one of our technical societies, has also pointed out that in England we were a long way behind the position this subject had occupied in Belgium as well as Germany, and in the testing of refractory materials for such purposes as the manufacture of fire-clays, firebricks, gas-making retorts, retorts used in zinc manufacture, and other lines of work.

At the same time he drew attention to the fact that in America refractory materials were being examined by methods which were not nearly so fully used in this country, and that a more careful study of the classification of the materials, following on the lines of Schone and including the microscopic examination of the particles, should be considered. The specimens tested were sized and separated so that it was possible to recognize the different mineral constituents in the fine clays and the coarser sandy particles. In that way it was possible to classify clay. Professor Turner thought it was Mr. Picard who found that two clays of the same chemical composition gave very different results. That was now a well recognized fact; in other words, it was well established that it was possible to have two clays of precisely the same ultimate chemical composition, and yet on account of the difference of size of the particles, and still more the different character of the minerals that made up those particles, to obtain from each of them entirely different results, both as regards the fusibility of the mass and the solubility of the alumina that was present.

Dr. A. B. Searle, in a paper read before the Royal Society of Arts in January 1915 on "Refractory Materials and the War," at the time stated that the manufacture of chemical porcelain, for instance, is almost unknown in Great Britain, and we have to depend for supplies of this ware on goods which are obtained more or less surreptitiously through neutral countries, such as Holland and Scandinavia.

These strictures, whilst no doubt correct at the time, have, I believe, been almost completely modified, partly on account of the excellent work carried on by Professor Herbert Jackson, F.R.S., also the special committees working in the London and Sheffield Universities who have dealt with this subject.

In the paper referred to Dr. Searle pointed out that whilst firebricks of equal refractoriness can be purchased in this country, they do not satisfy the tests which the Continental builders of coke ovens consider to be essential. He adds that "British firebrick manufacturers are making extensive efforts to overcome these objections, and are gradually increasing their ability to make firebricks to fit any reasonable specification. They have much to learn, however, though they have made much more rapid progress since the war began. Firebricks for furnaces and similar purposes where the specifications are less stringent can be made successfully in this country, though the prices of firebricks in extra-European countries before the war were largely in favour of those made in Germany. This was due to the much larger

works, organized on an entirely different basis and working on a system of 'dumping' which does not appeal to British manufacturers. It is a curious fact that with inferior materials to those commonly used in Great Britain, the Germans have turned out better firebricks and have been able to guarantee results to an extent which British firms have found impracticable. With competition less severe in some respects, British manufacturers are now turning their attention to improving the qualities of their goods, as in the past they have concentrated their minds on the production of cheap bricks. With adequate technical assistance of a kind not generally available they will be able to make great improvements in quality, and should, in time, be able to produce better bricks than any now on the market."

Dr. Searle also stated that "the chief difference between British and German refractory materials may be traced to the difference in the ownership and management of the firms. In this country refractory materials are chiefly made by men who have worked themselves up from a small beginning—or the descendants of such men—their chief characteristic being that of a workman whose knowledge and experience have been gained almost entirely in the workshop, and whose theoretical knowledge—either of chemistry, physics, or mechanics—is almost negligible. The German manufacturers of refractory materials, on the contrary, have almost invariably had a sound training in chemistry and engineering; they approach the manufacture from an entirely different point of view, namely, that of the user turned manufacturer. Consequently they are more impressed with the needs of the user, whilst the British manufacturer is chiefly impressed with the difficulties of manufacture and the limitations imposed by his material. If once this bias could be overcome—and the only remedy is the better education of the manufacturers—there is no question that better refractory goods can be made in Great Britain than can be obtained from the Continent for the same price."

In view of these statements by some of our leading authorities it will be admitted that the Council of the Faraday Society can offer full justification for the holding of this important meeting and presenting a symposium of papers on the subject.

Value of the Present Discussion.—It is to be hoped that our meeting will arouse general attention in this country to the subject, specially as in ferrous metallurgy any improvements in practice which add to the increased life and efficiency of steel-melting furnaces mean more output in a given time, a point of such vital importance in this war-time. Those directing metallurgical operations cannot claim to put the burden of working out improved practice upon the workman; it is the "master" himself who must study out new developments. Let us hope, therefore, that out of this meeting will spring improved practice and progress in the art.

The writer would here take the opportunity of thanking all those who have helped to make this gathering a success, whether as regards the valuable Papers presented or the interesting sets of exhibits.

In our Committee we have had an indefatigable body of workers to this end, and I should also like to add my own thanks and of those present to our very hard-working Secretary, Mr. Spiers. When I first suggested a gathering for this purpose he at once threw himself whole-heartedly into the matter, and I am sure every one present will offer hearty congratulations upon the results attained.

Workers on this Subject.—Amongst others in this country who have taken special interest in the subject of refractories are the following: Dr. J. W. Mellor, of the Staffordshire County Pottery Laboratory, who has paid so

much attention to this question and who is now conducting a research for the Advisory Council of Scientific and Industrial Research; Dr. H. G. Colman, Chairman of the Joint Refractory Materials Committee of the Institution of Gas Engineers and the Society of British Gas Industries; Major F. J. Bywater, now on active service, who was formerly Chairman of the above-mentioned Committee, is the author of the excellent paper on "Refractory Material" read before the Institution of Gas Engineers, referred to later on in these remarks; Mr. F. W. Harbord, who is also engaged in conducting inquiries and researches with regard to refractories in connection with another Special Committee; Professor W. A. Bone, the Chairman of the Fuel and Refractories Committee of the British Association.

Professor W. G. Fearnside, of the Sheffield University, has paid special attention to this subject; Dr. B. G. H. Boswell, who will speak to-night on refractory sands; Dr. A. Strahan, the able Director, and Mr. J. Allen Howe, of the Geological Survey and Museum, are present with us this evening and have been good enough not only to prepare some interesting information, but also exhibits; Mr. Ezer Griffiths, M.Sc., who has done excellent research work for the National Physical Laboratory in this direction; Messrs. Cliff, Page, Searle, and several others who will contribute to the discussion to-night from the point of view of the manufacturers; also many others.

The Chief Refractories.—The following probably represents the chief refractories:—

- (a) Silica.
- (b) China clay.
- (c) Magnesite.
- (d) Dolomite.
- (e) Chromite.
- (f) Bauxite.
- (g) Graphite.
- (h) Zirconite.

There have been considerable importations into our country from abroad of refractories, when without doubt in most cases equally as good, if not better, material has been in our own country at our very door. Moreover, this subject not only interests the ferrous and non-ferrous metallurgist, but also the makers of the various pottery, porcelain, and other similar wares. As an example, my own firm can plead guilty to having purchased material from abroad when it was at home and near at hand; I believe there are many others who would have to admit the same impeachment.

We have, therefore, specially to thank Dr. Strahan, Mr. J. Allen Howe, and Dr. Lamplough, of the Geological Survey and Museum, Jermyn Street, who have quite recently taken up the subject most vigorously and shown that at home in our own kingdom we possess much more valuable stocks of raw products to be used for the purpose of refractories than has been ordinarily imagined.

Professor W. R. Dunstan, F.R.S., of the Imperial Institute, has also given attention to this subject and has sent exhibits for this evening's proceedings.

Ganister.—The great importance of obtaining a good refractory is shown by the fact that the first development on a large scale of the Bessemer process in Sheffield was chiefly because there happened to be in that city a particularly fine quality of material known as "ganister." Sir Henry Bessemer could not find material suitable for lining his converters, in which

there is a combination of not only high temperature but slagging and erosive action. Sheffield ganister was found to meet this condition better than any other material, thus enabling Bessemer to carry his process into practical working success.

The following is a typical analysis of ganister :—

Silica	...	...	...	...	...	95	per cent.
Alumina	...	...	...	...	...	2	"
Iron oxide	...	...	...	...	...	0.5	"
Lime	...	...	...	...	...	1.00	"
Magnesia	...	...	...	...	...	0.6	"
Water	...	...	...	...	...	1.75	"

This material has been used for several generations to line the furnaces, known as "pot holes," in which Sheffield crucible steel is made, and it is still unsurpassed for this purpose.

Standard Specifications.—The pamphlet on *Standard Specifications for Refractory Materials*, published by the Institution of Gas Engineers in 1912, is of special interest in connection with the important subject being considered this evening, and it is being reprinted (by kind permission) as an Appendix to the present symposium. (See p. 264.)

Mr. Bywater's Paper.—An important paper was also read about the same time before the Institution of Gas Engineers by Mr. Frederick J. Bywater on the question of refractory materials. This paper is one of the most valuable contributions on the subject which the writer has seen, and by the kindness of the Institution of Gas Engineers this paper is being reprinted as a fitting Introduction to the present collection of Papers. (See p. 116.)

Method of Testing Bricks.—In one of the American papers reference is made to a simple but fairly effective method, shown by the following figure (Fig. 1), of testing refractory bricks, which has been brought forward by the Armstrong Cork and Insulation Company, of Pittsburg, Pa. Their experiment is carried out by playing the hottest flame obtainable, Bunsen burner or other gas jet, against the face of the brick to be tested. The surface naturally becomes white hot, but if the brick is not of the highest quality it will conduct the heat too quickly and soon become too hot to be held. This experiment could easily be carried out upon a brick of special qualities and a firebrick or common red brick, so that comparison is readily obtained.

The maker claims that he produces these bricks chiefly from diatomaceous earth (in whose fronds are secreted very large quantities of silica), which he states is one of the best non-conductors of heat known. The exact nature of this earth is not mentioned, but no doubt before long it will be possible to obtain supplies in this country, so that tests can be carried out.

It is claimed for this Nonpareil insulating brick that its insulating efficiency is ten times that of either common or firebrick, also that one 4½-in. course installed in the walls, arches, and bottoms of furnaces, ovens, boiler settings, hot-blast mains, and kindred high temperature equipment, will reduce the loss of heat as much as would 45 in. of ordinary brick. This is a strong statement, but the firm seems willing to prove that it is correct.

Dr. Percy.—It should be borne in mind that it was in Jermyn Street, where Dr. Strahan is now the Director, that Dr. Percy, to whom all of us still owe so much in our metallurgical education and training, laboured for so many years at the Royal School of Mines. In Dr. Percy's justly renowned work on metallurgy, when speaking of that portion relating to refractory materials, he said, "We must give the devil his due that we are probably indebted to the Germans to a greater extent than is commonly supposed for

the development of our mineral resources, since the introduction of German miners and metallurgists into England about three centuries ago, through the wisdom of Elizabeth."

In his work he only devotes a small space to refractory materials, including portion of a chapter on fire-clays. In this is given the following analysis, made in 1860, of the famous Dinas bricks:—

Silica	...	...	...	...	...	97 to 98½ per cent.
Alumina	...	...	...	...	...	0·75 to 1·50 „
Protoxide of iron	...	...	...	...	...	0·20 to 0·50 „
Lime...	...	...	...	...	...	0·20 „

Past Information on Refractories.—As an example of the scarcity of information, I have looked over some of the principal works on metallurgy and find that but little space or attention has been given to it.

Kohn in his book *Iron and Steel Manufacture* (1868) has an excellent chapter on "Moulding Sands," and there deals with refractories. He gives the following brief but on the whole accurate interpretation, which is the more remarkable seeing it was nearly fifty years ago, of the parts played by the different constituents of refractories.

The higher the proportion of silica the more refractory the substance, but its cohesion is then lessened, it is difficult to form it into a compact body, the moulds crack in drying and are liable to be destroyed by currents of metal running into them.

Alumina and magnesia are the substances which render the mass cohesive and plastic; but the excess of the former substance lessens the refractory qualities of the mould, it being subject to vitrification at a high temperature. Magnesia is highly refractory, and forms an excellent cement for silicious sand, but its quantity is limited by the necessity of keeping the whole mass porous for the escape of gases from the liquid metal.

The presence of metallic oxides in the sand always impairs its refractory qualities; still more undesirable is the presence of lime. Lime, if present as carbonate, will give off its carbonic acid at a high temperature, causing bubbles; if present as silicate or caustic lime, it will vitrify in contact with the sand. Similar results are produced by the metallic oxides.

He also describes, with great solemnity, how an important fire-clay mixture was brought over to this country from Bochum, called Riepe's mixture, by the Sheffield firm then known as Naylor, Vickers & Son, the working of which was a great secret.

Professor Howe, in his great work on *The Metallurgy of Iron*, gives some useful information, but only with regard to refractories such as used in the Bessemer process; that is, he deals chiefly with refractories in their bearing upon linings for Bessemer converters.

Professor Bradley Stoughton, in his *Metallurgy of Iron and Steel*, beyond two or three pages of general references, says very little.

Sir William Roberts-Austen, in his *Introduction to the Study of Metallurgy*, gives a few useful pages on general questions relating to refractories, but nothing of a very definite nature.

Refractories for Furnace Linings.—There are three classes of refractory materials now used—

- (a) Acid ... Dinas rock, ganister, fire-clays.
- (b) Basic ... Dolomite, magnesite.
- (c) Neutral ... Bauxite, chrome, iron ore, graphite, and a few fire-clays.

On satisfactory acid linings depend the acid steel process, such as the acid, Bessemer, and acid open hearth.

On satisfactory basic linings the success of the basic steel process practically depends, as in the presence of acid linings the necessary dephosphorization cannot take place, any phosphorus oxide formed being converted and again deposited in the bath.

Neutral linings, whilst possessing certain advantages, are usually very expensive and cannot be easily applied. On the other hand, in electric furnaces acid linings can be used if desired; nevertheless, basic, neutral, and zirconia linings are found to give much better results, hence the importance of a study of their application to this special purpose.

For crucible work there is still only the choice of two materials; the ordinary Sheffield clay crucible made of what is called pot clay, which is a mixture of fire-clay, china clay, a little carbon, and sometimes small quantities of other special materials. The usual mixture is two-thirds raw and one-third burnt clay.

Plumbago crucibles are produced in large quantities, being composed of fire-clay and graphite suitably mixed. The objection to the use of these crucibles is that naturally in melting steel considerable carbonization often takes place, and material cannot be obtained of the same uniformity as that melted in the ordinary type of Sheffield crucible, which has been used ever since the time of Huntsman. It is an open secret that this is the reason for the uniformity of what is known as Sheffield crucible steel, which steel retains its position in the markets of the world.

Large quantities of millstone grit are found in the moor districts near Sheffield. Howe points out that in some cases blocks of millstone grit have been used with fair results.

With reference to bauxite, Professor H. Le Chatelier in a recent letter to the writer states that he considers this material of great importance. He points out that his father studied this matter very closely as far back as 1870, but found that the excessive porosity of this material and its contraction militated against its successful use in the form of bricks. He attributes the difficulty to the bauxite not being sufficiently calcined, and therefore the subsequent shrinkage was not avoided. With the better means now available this can be done; a great improvement in practice should therefore result.

Professor Le Chatelier regards the bauxite bricks to have a much higher melting-point than those made from the very best silica.

This matter would appear to be well worth following up in this country. Messrs. J. H. Sankey & Son, Essex Wharf, Canning Town, London, E., are at the present time giving special attention to the subject.

Zirconia.—In addition to the ordinary and well-known refractories in which silica and alumina play the chief parts, the somewhat rare product zirconia has recently received much consideration. In the interesting book published not long ago on *The Rare Earths*, by Mr. S. I. Levy, B.A., B.Sc., a chapter is devoted to the study of zirconium and its oxides. In this reference is made to the importance of its use as a refractory. This oxide was isolated as a new earth from zircon, obtained from Ceylon by Klaproth in 1789. A little later the new earth was obtained also from hyacinth. The new oxide was examined in 1818 by Berzelius, who found it resemble alumina. The formula Zr_2O_3 was then given.

Whilst zirconium is fairly widely distributed in nature, it is in very small quantities, and can be rightly classed as one of the rarer elements. The most important source of the element was until quite recently the mineral zircon with its gem-varieties, hyacinth and jargon.

The chief source of the ore at present is the naturally occurring oxide, baddeleyite, which is almost pure zirconia ($ZrO_2 = 96.5$ per cent.). This was

discovered in 1892, particulars of which are given by Fletcher in the *Mining Magazine* of 1893. This has been obtained from the pyroxenite sand of Sao Paulo, South Brazil, also in Ceylon and in Montana, U.S.A. Its melting-point is probably about $2,700^{\circ}\text{C}$., and at $3,000^{\circ}\text{C}$. it begins to volatilize.

Zirconia occurs in crystalline rocks, specially in granular limestone, schist, gneiss, syenite, and granite. The most frequent forms are the silicates of zirconium, ZrSiO_4 .

The chief localities are in alluvial sands in Ceylon, the Urals, in the gold districts of Australia, Brazil, and in many places in North America.

The late Dr. Sorby, F.R.S., of Sheffield, noticed in this mineral a peculiar absorption spectrum, and he first thought that it contained a new element, to which he gave the name of jargonium. It was, however, subsequently found that these spectrum lines were caused by the presence of uranium oxide.

It has been shown by Rieke in *Sprechsaal*, 1908, No. 41, that whilst the oxide is very suitable for the manufacture of highly resistant crucibles and other refractories, its use is restricted by the fact that it is somewhat easily reduced by carbon at high temperatures, forming the carbide.

It appears that as early as 1904 the use of zirconia was suggested for cutting muffles, retorts, and tubes which are required to withstand high temperatures. This was given in the German patent: Pyfahl, No. 156,756. In 1906 it was proposed by the Heræus Company, in their German patent, for the manufacture of crucibles in which rock-crystal (quartz) was fused for the preparation of quartz-glass, since zirconia is not attacked by molten silica. It promises to be of the greatest use in all cases where a very refractory material, stable towards the ordinary chemical reagents, is required.

Metallic zirconium has also been obtained by the calcium reduction process, introduced by Kuzel and Wedekind. Whilst zirconia is not reduced by powdered aluminium (Goldschmidt's process), alloys of zirconium and iron can be easily obtained by reduction of the mixtures of the two oxides by this method. It appears alloys containing up to 35 per cent. of zirconium can be obtained; this ferro-zircon, as it is called, has been to some extent recently replaced by ferro-titanium for the purification of steels. Several German patents have been taken out for this purpose.

It is also stated that any addition of small quantities of zirconium to steels (brass, copper, etc.) is said to secure sound castings, whilst increasing considerably the strength and resistance to acids of the metal.

For most of the above information the writer is indebted to Mr. S. I. Levy in his very excellent work entitled *The Rare Earths*.

Another very interesting article on the subject is that by Mr. H. Conrad Meyer, "Further Notes on the Refractory Properties of Zirconia," which appeared in the *Metallurgical and Chemical Engineering* of April 1915. Much useful information is there contained regarding heat tests, fire shrinkage, selection of binders, fire-clay bonds, and zirconia crucibles and similar shapes.

An analysis of zirconia was given in a previous paper in December 1914 by the same author, which was as follows:—

ZrO_2	...	...	...	...	...	84.10
SiO_2	...	...	...	...	...	7.74
Fe_2O_3	...	...	...	...	...	3.10
TiO_2	...	...	...	...	...	1.21
Al_2O_3	...	...	...	...	...	.66
Loss on ignition...	...	...	...	...	...	2.72

 99.53

The Foote Mineral Company of Philadelphia have paid a good deal of attention to this product. Zirconia, they say, owing to its high degree of infusibility, high resistance to basic or acid slags, low thermal conductivity, low coefficient of expansion, can be employed at the highest temperatures without the destruction of the furnace linings. The material is supplied as zirconium oxide, also in the form of cement affording a plastic bond when wet.

Much useful information with regard to zircon, zirconia, and zirconite, as it is often indiscriminately termed, is found in Dana's book *Minerals and How to Study Them* (1902), also in Mendeléeff's *Principles of Chemistry* (1905). Incidentally the latter points out that zirconium compounds are generally prepared from powdered zircon by fusing it with sodium carbonate and then boiling in water. An insoluble white residue is obtained consisting of a compound of the oxides of sodium and zirconium, which is then treated with hydrochloric acid and the solution evaporated to dryness. The silica is thus converted into an insoluble form, and zirconium chloride obtained in solution. Ammonia precipitates zirconium hydroxide from this solution as a white gelatinous precipitate, $\text{ZrO}(\text{OH})_2$. When ignited, this hydroxide loses water, and in so doing undergoes spontaneous recalcination and leaves a white infusible and exceedingly hard mass of zirconium oxide, ZrO_2 , having a specific gravity of 5.4 (in the electric furnace, ZrO_2 fuses and volatilizes like SiO_2 —Moissan). Owing to its infusibility, zirconium oxide is used as a substitute for lime and magnesia in the Drummond light.

In Sterry Hunt's excellent works, *Systematic Mineralogy* (1891) and *Mineral Physiology and Physiography* (1891), some useful information is also given.

Bibliography.—With reference to the bibliography, it will be seen that information in this form is quite scanty. In view, therefore, of the importance of the subject, I have prepared from my own series of references, extending over a period of some thirty years, and taken from the technical and scientific press, the various papers shown in the accompanying Tables I and II, the former comprising books on the subject, and the latter references in the technical press. Should any member of the Society like to refer to any particular book or extract referred to in these tables, they are with pleasure at his service.

The divisions of these press references, covering pamphlets, papers, and cuttings, are in the following order—

- (a) Firebricks and clay products.
- (b) Silica products.
- (c) Magnesite products.
- (d) Chromite products.
- (e) Bauxite products.
- (f) Zirconia.
- (g) Graphite.
- (h) Comparative tests.
- (i) Miscellaneous.

There are in all 197 papers, of which 64 are British, 14 French, 67 American, and 46 German.

EXHIBITS.

In addition to the excellent and complete set of exhibits from various members of our Society, also other friends and firms, it has occurred to me that in these introductory remarks to the symposium of Papers now presented

FIG 1.

This simple test will demonstrate the heat insulating quality of various types of firebricks.

MAGNESITE NOZZLE.

FIG. 2.—Before and After Use. No. of Castings made, 77. Total weight, 28 tons.

FIRE-CLAY NOZZLE.

FIG. 3.—Before and After Use. No. of Castings made, 77. Total weight, 28 tons.

FIRE-CLAY STOPPER.

FIG. 4.—Before and After Use. No. of Castings made, 77. Total weight, 28 tons.

FIG. 5.—Worksop Yellow Sand (not treated with HCl). $\times 15$.

FIG. 6.—Worksop Yellow Sand (after treatment with HCl).

FIG. 7.—Dutch Silver Sand. $\times 15$.

FIG. 8.—Scotch Silver Sand. $\times 15$.

FIG. 9.—Back Facing Sand. $\times 30$.

FIG. 10.—Scotch Fire-clay. $\times 30$.

FIG. 11.—Worksop Red Sand. $\times 15$.

FIG. 12.—Leighton Buzzard Sand. $\times 15$.

FIG 13.—French Red Sand. $\times 15$.

it would be well to exhibit specimens of refractory materials, also those which are definitely known to have given good and bad results, with a view to obtain some discussion with regard to reasons for the respective satisfactory and unsatisfactory behaviours. Table III gives a full description of these, from which it will be seen that analysis only does not by any means tell us all we want to know. Evidently there are physical conditions prevailing in these refractories which we do not yet understand, just as in bars of the same steel and composition one may obtain good and bad tensile and elongation qualities, the causes of which we are, however, now fairly well able to detect. Whilst, therefore, it is not analysis alone which will tell us why one refractory is good and another bad, we have to look for the physical conditions of the respective combinations of the elements present, that is, apart from their chemical constituents.

I therefore add the following information which has come to me from my company's laboratories in Sheffield. I give these fully because they represent the practical views of those handling daily various types and qualities of refractories.

Sand for Open Hearth Bottoms, of which both British and Belgian specimens are submitted.

Whilst Belgian sand for open hearth furnace bottoms was in universal use before the war, when these supplies were stopped it was necessary to experiment with British sands. This was at first done by mixture with Belgian material, but ultimately a British sand has been found to give practically the same results as the foreign product since its properties were correctly understood.

In this respect I would suggest that those in difficulty and doubt would often be able to obtain most interesting and valuable information from Dr. Strahan, the Director of the Geological Survey and Museum in Jermyn Street.

Silica Bricks.—One of the chief difficulties experienced with silica bricks is insufficient burning, known to furnace men as "half-bakes." Such bricks flux almost as readily as firebricks. If such bricks are not detected before putting in the furnace, it may mean shutting down the furnace for repairs, although the rest of the furnace is quite good.

Fire-clay Stoppers.—Stoppers are quite as important as nozzles. Magnesite does not appear to make a successful stopper as hitherto manufactured, owing to its liability to crack and spelch. When using magnesite nozzles it frequently happens that the fire-clay stopper ends collapse during the casting, and fused pieces pass through the nozzles. Fire-clay nozzles wear badly as compared with magnesite, and usually the orifice is double the size after similar work, which means that a good deal of silica has entered into the steel and is the cause of subsequent trouble.

As regards the above experiments I am this evening submitting specimens of—

(a) A bad fire-clay stopper and the slag produced after passing through the nozzle.

(b) Fire-clay nozzle for comparison with a good magnesite nozzle (see next paragraph). Both these have done the same work.

Magnesite Nozzles, of which both good and bad specimens are submitted.

Fig. 2 shows magnesite nozzle before and after use. No less than 77 separate pourings were made with this nozzle from a ladle containing 28 tons of open-hearth carbon steel. It will be seen that the pouring hole in the nozzle had a diameter of 1 in. before use; after 28 tons of steel had run through this the diameter still remained 1 in.

As a comparison, Fig. 3 gives the results obtained with an ordinary fire-clay nozzle. With this 77 pourings were made from a ladle containing 28 tons of open-hearth steel. It will be seen that the diameter of this ordinary fire-clay nozzle was increased to no less than 2 in. It is therefore quite clear how intermingled slag is found in steel; the silica and alumina is slagged off and is carried into the steel ingot or casting being poured, some of it floating to the top, but in some cases it remains on the side of the ingot, or even embedded in the steel.

In Fig. 4 an ordinary fire-clay stopper is shown before and after use.

Magnesite nozzles have given excellent results when used for a large number of castings from one heat, also with steels containing 0.90 per cent. of manganese and upwards. This is due to the fact that such steels have a severe chemical action on the fire-clay nozzles. The use of magnesite for nozzles is not a new idea, but owing to the more stringent specifications in the manufacture of steel this use of magnesite is now being brought forward. One of our nozzle experiments was made with a combination of magnesite and fire-clay, but this was not successful, as the acid flux from the fire-clay attacked the magnesite and caused too much increase in the size of the orifice in the nozzle. It is also extremely important that these nozzles should be perfectly dry. The bad sample exhibited is an example of a nozzle delivered wet, which gave way in the middle of casting a 25-ton heat.

Plumbago Stoppers and Nozzles, specimens of each of which are submitted.

A number of these have been tested, and the results obtained so far have been no better than those with fire-clay.

Magnesite Bricks.—As is well known, this country was unfortunately, partly through ignorance and lack of enterprise, to some extent dependent upon Austrian magnesite. Supplies have also been obtained from Grecian mines.

Dolomite Bricks.—For use on the walls and roofs of electric furnaces, these would be invaluable if means could be devised to prevent perishing.

Zirconia.—Experiments are now in progress with this material, with regard to the practical application of which it will no doubt be possible to submit fuller information later on.

ANALYSES.

In addition to the above I have also prepared from our laboratory records a large number of analyses of British and foreign refractories, which are shown in Tables IV, V, VI, VII, and VIII. From these it will be seen that they come from "all the ends of the earth"; not only British, but Belgian, French, German, and American. In view of the scanty nature and little work which has been done in this direction, I trust this information will be found of interest to those within the Empire who are interested in this important subject.

I have had prepared a few photomicrographs, shown in Figs. 5–13, as an illustration of the use of microscopy in the study of refractories. A good deal of attention has been paid to this side of the subject in America, where useful papers have been read before the American Foundrymen's Association with regard to such examination of refractory materials on sands of various kinds.

The following is only put forward in a tentative way and with a view to arouse interest on this particular side of the research with regard to refractories. Professor Fearnside, of the Sheffield University, is also dealing with this subject in his excellent paper on the "Application of Petrographic Methods to the Study of Refractory Materials."

Whilst it has been stated that analysis is not by itself sufficient guide, it may be that the methods of determining the chemical composition of refractories have not been altogether perfect, and that in this respect there is room for improvement. On the other hand, it must still be borne in mind that, as in the case of iron, steel, and other products, analysis is the basis and basic principle of our knowledge of such materials.

Table IX gives the description of the sands of which I submit photomicrographs, together with the remarks upon these.

It should be mentioned that the sands from which the photomicros shown in Figs. 6, 11, 12, and 13 were prepared were washed with hot dilute HCl. This is to clear the grains from colouring matter, so that they stand out sharply in the photomicros in order that their size and varying capacity can be clearly seen.

Conclusion.—This subject of refractories has been treated in the past far too much in an empirical manner. Whilst in this country much has been done from the time of Wedgwood and others, yet let us now show the world that we intend to lead the way, and take up this important branch of metallurgy in a proper scientific manner. Much research is required in addition to that carried on at the works of the manufacturers. Research centres such as the National Physical Laboratory, the Metallurgical Section of the Sheffield University, and still more recently the Advisory Council for Scientific and Industrial Research, are all prepared to render help, either by carrying out actual researches or finding research grants to those they are satisfied will wisely spend such grants and make use of such information. It is to be hoped that this evening's symposium of Papers will result in extended knowledge on this important subject. If so, the Council of the Faraday Society will be well repaid for the trouble they have taken in its preparation.

In conclusion, I take this opportunity of thanking my assistants, Messrs. Dawson, Swift, Elliot, Main, Mortimer, and others, for their useful help in the preparation of this introductory address.

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TABLE II.

Date.	Title.	Author.	Publication.	Country.	Description.
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22 February	Determination of Fireproof Qualities of Clay	Seger, Dr.	—	Germany	Pamphlet
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15 June	Variation Found in the Use of Firebricks	—	Stahl und Eisen	Germany	Cutting
22 October	Notes on the New Jersey Firebrick Industry	Ries, H.	Iron Age	United States	Cutting
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5	March	1914	Tests for Firebrick and Clay ...	Mowat, J. F.	Iron Trade Review	United States	Cutting
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29	January	1915	Refractory Materials and the War	Searle, A. B.	Journal Royal Society of Arts	Great Britain	Extract
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TABLE II (continued).

Date.	Title.	Author.	Publication.	Country.	Description.
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25 September	Thermal Conductivity of Refractories	Dougill, G., Hodsmann, H. J., & Cobb, J. W.	Society of Chemical Industry	Great Britain	Extract
—	Bricks for High Temperatures ...	Heisel, W. A.	Ohio Society of Engineers	United States	Pamphlet
8 January	Pyrometers, Fusible Pyrometers, Seger Cones	Granger, A. (Chief of Testing Laboratory, National Sévres Factory)	—	France	Pamphlet
20 January	Grids for Hot Blast Producers ...	—	Stahl und Eisen	Germany	Cutting
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15 June	High-temperature Furnace Cement	Quigley, W. T.	Met. and Chem. Eng. Iron and Coal Trades Review	Great Britain	Extract
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13 July	Testing Firebrick ...	Nesbitt, C. E., and Bell, M. L.	Iron Age	United States	Cutting
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Date.	Title.	Author.	Publication.	Country.	Description.
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1913	La Silice	Chatelier, H. Le	Revue Univle. des Mines	France	Cutting
1913	Silica Quartzite	Endell, K.	Stahl und Eisen	Germany	Cutting
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1890	Magnesite Lining for O.H. Furnaces	—	Stahl und Eisen	Germany	Cutting
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1890	Lining of Basic Martin Furnaces with Magnesite	Lezius, H.	—	Germany	Pamphlet
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—	—	1893	Magnesite Bricks for Martin Furnaces	Negris, P.	La Metallurgie	France	Extract
14	April	1893	Magnesia Firebricks	—	Engineering Journal of Society of Chemical Eng.	Great Britain	Cutting Extract
30	November	1893	Magnesite as a Refractory Material	—	Engineering and Mining Journal	United States	Cutting
11	July	1903	Magnesite : Its Uses and Value	Schnatterbeck, C. C.	Sydney Morning Herald	—	Cutting
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—	1907 Graphite, its Properties, Occurrence, Refining and Uses	Cirkel, F.	Ottawa Dept. of Mines	Canada	Pamphlet
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19	December	Volcanic Cement	Piron, H. J.	—	Germany	Pamphlet
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TABLE II (continued).

Date.	Title.	Author.	Publication.	Country.	Description.
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December	1913 Refractories in the Iron and Steel Industry	Croft, H. W.	Iron Trade Review	United States	Cutting
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—	1914 Specific Heats of Refractory Products	Steger	Silikat Zeitschrift	Germany	Cutting
—	1914 Thermal Conductivity of Refractory Building Materials	Heyn, E.	Stahl und Eisen	Germany	Cutting
—	1914 Relative Thermal Conductivities of Silica and Clay Refractories...	Brown, G. H.	Trans. Amer. Ceramic Society	United States	Pamphlet
—	1914 Relative Thermal Conductivity of Silica and Clay Brick	Marshall, S. M.	Metallurgical & Chemical Engineering	United States	Cutting
24 April	1915 Fibrox ...	Weintraub, E	American Electrochem. Society	United States	Pamphlet
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—	1915 Thermal Conductivity of Refractory Materials	Dougill, Hodsman and Cobb	Journal Society of Chemical Industry	Great Britain	Pamphlet
—	1915 Thermal Conductivity of Refractories	Dudley, Jr., Boyd	Transactions American Electrochem. Society	United States	Pamphlet
4 April	1916 The Common Refractory Oxides ...	Sosman, Robert B.	Amer. Chemical Society and American Electrochem. Society	United States	Pamphlet

TABLE III.

Specimens of Refractories Exhibited at the Meeting of the Faraday Society on the 8th November, 1916.

Material.	Source.	Analysis.						Loss on Ignition and H ₂ O %	Used for	Remarks.
		SiO ₂ . %	Al ₂ O ₃ . %	Fe ₂ O ₃ . %	CaO. %	MgO. %	MnO. %			
A. Sands.										
Silver Sand	Holland	98.30	.70	.40	.80	.20	—	—	Open-hearth furnace.	This material is now replacing the Belgian and Dutch Sands.
English Silica Sand ..	Leighton Buzzard ..	98.90	.80	—	—	—	—	—	" " Foundry work. "	
Scotch Silver Sand ..	Glenboig	99.40	.60	—	—	—	—	—		
French Sand	France	82.90	7.00	4.70	1.10	.76	—	—	" "	
Red Sand	Worksop	87.50	5.65	2.57	.82	1.22	.18	1.95	" "	
Yellow Sand	Worksop	92.90	3.90	1.10	.20	.36	—	1.07	" "	
B. Silica and Ganister.										
Silica Rock	Holyhead	95.10	1.30	1.15	.76	.50	Tr.	—	Foundry work	Open-hearth, Converter, and other steel-making furnaces.
Raw Ganister	Sheffield	91.80	3.00	.72	1.43	.75	—	2.80	"	
Calcined Ganister ..	Sheffield	—	—	—	—	—	—	—		
C. Fireclay.										
Scotch Fireclay	Glenboig	62.00	28.00	2.50	.50	.50	Alkalies .50	6.50	—	Photomicro shown in Fig. 10.
D. Bricks.										
Fireclay	Sheffield	62.90	32.70	3.50	.90	.40	—	—	*This exhibit is a specimen of an insufficiently burnt Silica Brick.	
Silica	Dinas	95.80	1.30	1.90	—	—	—	—		
Magnesite	—	2.00	1.30	7.70	8.00	80.00	—	—		
Chromite	—	5.20	13.90	16.20	.78	9.22	Cr ₂ O ₃ 53.66	—		
Dolomite	—	3.30	—	—	53.50	36.00	—	—		
					SiC.					
Carbofrax	Niagara Falls ..	18.60	4.83	—	77.00	—	—	—		
Refrax	Niagara Falls ..	6.85	3.60	—	89.50	—	—	—		
Bauxite Brick	—	—	—	—	—	—	—	—		
Silica Brick	—	—	—	—	—	—	—	—		
E. Crucibles.										
Specimens of Materials used in Manufacturing Sheffield Clay Crucibles, including:—										
(a) China Clay		46.92	38.56	1.48	.25	.33	—	11.92		
(b) Derby Clay		48.10	34.85	2.75	.20	.75	—	11.99		
(c) Ordinary Clay		44.70	37.50	1.50	1.10	—	—	14.20		
(d) Coke Dust		Fixed C. 87.0; Hydro. C. 2.0; Ash 8.0; H ₂ O 3.0; S. in ash 1.0.								
Sheffield Clay Crucible, with lid (new and before use).										
" " " " (after use).										
Graphite Crucible, " with lid (new and before use).										
" " " " (after use).										
F. Stoppers and Nozzles for Ladles.										
Plumbago Stopper and Nozzle showing the condition after casting 15 tons of steel (40 separate taps).										
Fireclay	"	"	"	28	"	(77)	"	"	"	
Magnesite	"	"	"	28	"	(77)	"	"	"	

REFRACTORY MATERIALS

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TABLE IV.
English Refractories.

Name of Refractory.	Source.	Analysis.						Analysis made by		
		SiO ₂ .	Al ₂ O ₃ .	Fe ₂ O ₃ .	CaO.	MgO.	Alkalies.		Loss on Ignition and H ₂ O.	TiO ₂ .
Midlands.										
Silver Sand	—	98.2	0.85	0.55	0.57	0.37	—	0.15	—	Hadfield
Ganister ...	Sheffield ...	91.8	3.00	0.72	1.53	0.75	—	2.80	—	Hadfield
Moulding Sand	Worksop ...	86.7	7.13	1.67	0.54	1.00	—	2.30	—	Hadfield
Fire-clay ...	Stourbridge	65.0	22.0	2.0	0.50	—	0.50	10.0	—	Searle
Fire-clay ...	Shropshire	59.0	27.0	1.0	0.50	—	0.50	12.0	—	Searle
Firebrick ...	Stourbridge	69.0	27.30	1.86	0.27	0.32	0.91	—	—	Harbord
Firebrick ...	Leeds	78.35	13.46	4.40	2.32	1.80	—	—	—	Hadfield
Firebrick ...	Leeds	31.01	60.36	4.03	0.72	0.41	—	1.08	2.87	Hadfield
Firebrick ...	Stannington	62.90	32.70	3.50	0.90	0.40	—	—	—	Hadfield
Calcined Magnesite	Liverpool	0.80	—	1.85	2.50	94.40	—	—	—	Hadfield
Raw Magnesite	Liverpool	0.46	0.52	0.52	1.60	46.88	—	—	—	Hadfield
Dolomite Brick	Worksop ...	3.30	—	—	53.50	36.00	—	—	CO ₂ 49.5	Hadfield
Magnesite Nozzle	Farnley ...	4.54	1.45	1.36	4.56	87.69	—	0.40	—	—
Wales.										
Dinas Sand	Dinas	98.00	1.00	1.00	—	—	—	—	—	Searle
Kidwelly Sand	Kidwelly ...	97.2	0.60	1.00	0.28	0.32	—	—	—	Hadfield
Ganister ...	Kidwelly ...	95.5	2.00	0.46	0.66	0.54	—	0.70	—	Hadfield
Fire-clay ...	Holyhead	48.06	44.04	1.26	—	—	—	0.14	4.60	Hadfield
Firebrick, Dinas	Dinas	95.81	1.34	1.86	—	—	—	—	—	Hadfield

TABLE IV (continued).
English Refractories (continued).

Name of Refractory.	Source.	Analysis.							Analysis made by	
		SiO ₂ .	Al ₂ O ₃ .	Fe ₂ O ₃ .	CaO.	MgO.	Alkalies.	Loss on Ignition and H ₂ O.		TiO ₂ .
Scotland and North of England.										
Sand	...	99.4	0.60		—	—	—	0.10	—	Hadfield
Ganister	...	94.0	4.0	—	—	—	—	—	—	Hadfield
Fire-clay	...	52.0	28.0	1.5	0.5	0.5	1.5	16.0	—	Searle
Fire-clay	...	62.0	28.0	2.0	0.5	0.5	0.5	6.5	—	Searle
Fire-clay	...	48.59	35.82	1.56	0.30	0.29	—	11.57	—	Hadfield
Firebrick	...	63.00	32.00	2.85	0.79	0.36	0.94	—	—	Harbord
South of England.										
Ganister	...	87.0	5.95	3.05	1.05	0.55	—	2.50	—	Hadfield
Loam Sand	...	83.0	7.02	4.28	1.15	0.80	—	—	—	Hadfield

REFRACTORY MATERIALS

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TABLE V.
Foreign Refractories.

Name of Refractory.	Source.	Analysis.						Analysis made by.		
		O ₂ .	Al ₂ O ₃ .	Fe ₂ O ₃ .	CaO.	MgO.	Alkalies.		Loss on Ignition and H ₂ O.	TiO ₂ .
Germany.										
Herzogenrath Sand	—	98.30	1.50	0.70	Trace	0.32	—	—	—	Hadfield
Raw Ganister	Westphalia	95.60	1.76	2.14	0.32	0.20	—	—	—	Hadfield
Fire-clay	Coblenz	48.10	33.22	2.68	0.86	0.32	—	16.00	—	Hadfield
Fire-clay	Grusonwerk	43.80	34.54	0.76	1.03	0.70	—	19.50	—	Hadfield
Fire-clay	Krupp	68.0	24.55	2.50	0.85	—	1.30	0.10	2.00	Hadfield
Magnesite Brick	Schweidnitz	1.20	1.30	7.50	4.50	85.20	—	—	—	—
Calcined Magnesite	Coblenz	4.30	0.40	11.00	4.10	86.30	—	—	—	—
Magnesite Brick	Coblenz	2.23	1.29	7.91	11.07	73.48	—	—	0.23	—
France and Belgium.										
Glass Sand	Belgium	98.3	0.70	0.40	0.80	0.20	—	—	—	Hadfield
Moulding Sand	France	85.8	6.80	2.40	0.82	0.50	—	3.50	—	Hadfield
Moulding Sand	France	82.9	7.00	4.70	1.10	0.76	—	—	—	Hadfield
Calced Magnesite	France	—	—	—	—	83.50	—	—	—	Hadfield
American.										
Silica Sand	Cheshire, Mass., U.S.A.	97.80	1.06	0.30	0.45	0.32	—	—	—	Hadfield
Silica Sand	High Bridge, N.J.	96.75	1.45	1.05	0.57	0.25	—	0.50	—	Hadfield
Ganister	High Bridge, N.J.	93.25	3.89	0.86	0.42	—	—	1.16	—	Hadfield
Moulding Sand	Newport, U.S.A.	81.60	6.10	4.85	1.11	1.15	—	3.30	—	Hadfield
Moulding Sand	New York, U.S.A.	80.60	10.40	4.30	1.20	1.00	—	2.30	—	Hadfield
Moulding Sand	High Bridge, U.S.A.	82.40	6.08	2.12	0.82	1.50	—	7.10	—	Hadfield
Fire-clay	Mineral Point, O., U.S.A.	52.52	31.84	0.67	0.50	0.19	0.59	11.68	1.68	Ries
Fire-clay	Woodbridge, N.J.	51.56	33.13	0.78	Trace	Trace	Trace	12.50	1.91	Ries
Fire-clay	New Brighton, Pa.	62.89	21.49	1.81	0.38	0.56	2.52	8.74	1.82	Ries
Succa Sunna Sand	High Bridge	96.75	1.45	1.05	0.57	0.25	—	0.50	—	Hadfield

REFRACTORY MATERIALS

TABLE VI.
Chrome Iron Ore.

Nature of Material.	Analysis.						Remarks.
	SiO ₂ .	Al ₂ O ₃ .	Iron Oxides.	CaO.	MgO.	Cr ₂ O ₃ .	H ₂ O.
Chrome iron ore ...	2.25	3.01	35.82	4.20	2.60	51.54	—
	2.00	19.25	14.70	3.75	17.66	41.67	0.97
						Harbord	Typical analysis
						Macfarlane	Typical analysis

Chrome Bricks, Bauxite Bricks.

Nature of Material.	Analysis.							Remarks.
	SiO ₂ .	Al ₂ O ₃ .	Iron Oxides.	CaO.	MgO.	Cr ₂ O ₃ .	H ₂ O.	Analysis Made by.
Chrome brick ...	5.20	13.90	16.20	0.78	9.22	53.66	—	Macfarlane
	13.60	14.88	15.72	—	—	27.65	—	
Bauxite brick ...	3.50	51.40	38.37	2.46	0.79	—	—	Macfarlane
	35.80	55.80	3.40	0.90	—	—	3.08	
								Typical analysis Sample from Schweidnitz
								Typical analysis

REFRACTORY MATERIALS

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TABLE VII.

Titanium Ores.
(From *Rare Earth Industry*, Johnstone.)

	PICOILMENITE.		ILMENITE.		SPHENE.	STRUVERITE.
	Ceylon.		Caroline.	Ilmen Mountains.		
	Per cent.		Per cent.	Per cent.	Per cent.	Per cent.
TiO ₂ ...	64.72	52.75	45.93	40.82	45.74	45.74
FeO ...	16.59	33.08	36.52	—	8.27	8.27
Fe ₂ O ₃ ...	2.66	8.08	14.30	—	—	—
CaO ...	—	—	—	28.08	—	—
MgO ...	15.76	5.33	0.59	0.40	—	—
SiO ₂ ...	0.70	—	—	30.10	0.20	0.20
MnO ...	0.42	—	2.72	—	Trace	Trace
Nb ₂ O ₅ ...	—	—	—	—	6.90	6.90
Ta ₂ O ₅ ...	—	—	—	—	35.96	35.96
SnO ₂ ...	—	—	—	—	2.67	2.67
Water ...	—	—	—	0.54	0.50	0.50

Zirconium Ores.(From *Rare Earth Industry*, Johnstone.)

	ZIRCON.		BADDELEYITE.			
	Ceylon.	Norway.	Brazil : Glassy Variety.	Brazil : Stony Variety.	Brazil : Pebbles.	Brazil : Commercial Variety.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
ZrO ₂ ...	66.35	64.05	94.12	88.40	74.48	68.93
Fe ₂ O ₃ ...	0.83	2.85	3.22	4.07	10.26	3.59
TiO ₂ ...	—	—	0.98	3.12	1.35	0.60
CaO ...	—	—	—	—	—	—
SiO ₂ ...	32.35	32.53	2.41	5.89	14.08	26.30
H ₂ O ...	0.23	—	—	—	—	0.80
						Per cent.
						98.90
						0.82
						—
						0.06
						0.19
						0.28

TABLE VIII.

Carborundum, Graphite.—Carborundum Bricks.

	SiO ₂ .	Al ₂ O ₃ , Fe ₂ O ₃ .	SiC.	Analysis Made by
"Carbofrax" Brick ...	18.60	4.83	77.0	Hadfield
"Refrax" Brick ...	6.85	3.60	89.50	Hadfield

Analysis of Used Graphite Crucible.

	Per cent.					
Free carbon ...	...	...	...	...	...	38.92
Silicon carbide ...	...	...	...	...	...	20.14
Iron oxide (FeO) ...	...	...	...	...	...	4.37
Alumina ...	...	...	...	...	...	15.11
Free silica ...	...	...	...	...	...	20.47
Lime ...	...	...	...	...	...	0.98

(From Johnson, *Analysis of Special Steels, Steel Making Alloys, and Graphites.*)

TABLE IX.

Photo-micro Fig. No.	Description.	Source.	Remarks on Photomicrograph.
5	Yellow Sand ...	Workshop	(Not treated with HCl) The effect of the colouring matter on the grains is very clearly shown on comparing them with the photographs of the silver sands. The grains are generally very rounded and of about the same size as the Scotch silver sand.
6	Yellow Sand ...	Workshop	(After treatment with HCl) Medium and small-sized grain of well rounded form.
7	Silver Sand ...	Holland	The grains are shown to be very regular in size and smaller than either Scotch or Workshop sand.
8	Scotch Silver Sand	Glenboig	White, almost transparent grains of irregular size. The grains are distinctly coarser than those of the Dutch silver sand, and generally more angular in form.
9	Back Facing Sand	—	The sand as seen by the naked eye has a dark grey-brown colour. The microscope shows this sand to consist of many-sized grains of various colours, from transparent ones to those quite black and opaque.
10	Scotch Fire-clay...	—	Light grey amorphous material. This, it must be remembered, has been ground.
11	Red Sand ...	Workshop	A fine grain mixed with a medium-sized one—two distinct sizes clearly marked.
12	Sand ...	Leighton Buzzard	Well rounded grains of large and uniform size.
13	Red Sand ...	France	Very small grains—very uniform; many are transparent and of angular character.