Some Recent Services of Metallurgy to Engineering.[1]

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IN honouring me with the invitation to deliver the James Forrest lecture this year—the thirty-third of the series—the Council of this Institution expressed a desire that I should deal with recent advances in metallurgy which have a bearing on engineering practice. It is twenty-one years since my distinguished predecessor Sir Robert Hadfield delivered the last lecture in which metallurgy constituted the main subject, and it would seem convenient, therefore, that I should deal with the progress made since that date.

FLOTATION.

As regards ore-treatment, water-concentration is eminently satisfactory in the concentration of ore containing relatively coarse and granular mineral and a light gangue. Chemical treatment is equally satisfactory when the valuable mineral crushes to powder and the gangue is not soluble. Between these two lies the field of flotation, this method of concentration being effective both in the presence of a heavy gangue and a fine mineral. It belongs to the present era of mining, which dates back to the exploitation of the rich auriferous gravels of California and Australia about the middle of the nineteenth century, though the first flotation process to be applied commercially was that developed by Elmore in London in 1898. He was, moreover, the first to apply the selective action of oil to a pulp flowing freely from a wet-crushing machine. Put briefly, in flotation the mineral is floated on an air froth, while the gangue sinks to the bottom, whereas in concentration the mineral sinks to the bottom and the gangue is floated away.

There are three main types of froth-flotation machines, known respectively as the mechanical, pneumatic, and cascade. Of these the mechanical flotation machine is the widest applied. The standard pattern machine has a capacity of about 1·25 tons per square foot of machine area per day. A machine of ordinary size will treat about 400 tons per day, and require about 100 H.P.

Flotation first established itself by the recovery of lead and zinc-blende from an association with heavy gangue at Broken Hill, New South Wales, its success being complete about 1910. Whereas with water concentration, before the advent of flotation, the recovery was only 60 per cent. of lead, less of silver, and none of the zinc, the recoveries to-day are about 85 per cent. of the lead, 65 per cent. of the silver, and 83 per cent. of the zinc. These percentages do not include the lead in the zinc concentrate, or the zinc in the lead concentrate. The cost of flotation is about 6s. per ton, and that of complete dressing about 9s. per ton. At the Butte, Superior, Montana, the present recovery is about 92 per cent. from an ore assaying about 17 per cent. of zinc, flotation being responsible for about three-quarters of the production.

At Anaconda, where in 1915 the recovery of copper by water was 78 per cent., a flotation equipment was erected in the expectancy of raising the recovery to more than 90 per cent. This expectation has been realised. At Utah-Leasing, Newhouse, Utah, a tailing dump containing about 700,000 tons, assaying about 0·7 per cent. of copper, was successfully treated by flotation, the concentrate assaying about 18 per cent., and the final tailing about 0·2 per cent. At Calumet and Hecla at Lake Superior, a conglomerate of ore containing native copper is treated by a flotation plant having a capacity of about 2000 tons per day. From this material, which contains less than 1 per cent. of copper, a recovery of 60 per cent. is made at a cost of about 10d. per ton.

To-day, in fact, flotation is applied on practically every important non-ferrous mining field. Tin alone has not yet benefited by it. In general terms, where formerly water concentration yielded a 65 per cent. to 70 per cent. recovery, the adoption of flotation has raised the recovery to from 80 to 85 per cent.

REVERBERATORY FURNACE SMELTING.

As the finely divided concentrate cannot be smelted in a blast furnace, one of the principal consequences of the development of the flotation process has been the necessity of designing a new type of furnace. This has been developed from the original small reverberatory furnace, used many years ago in copper smelting in Swansea. The modern furnace, however, is so much larger and its method of working so different that the process is really a new one.[2] The fuel used in the modern large reverberatory furnace is pulverised coal or fuel-oil, depending upon the relative cheapness of the two fuels. When pulverised coal is used, it is ground so that 80 to 90 per cent. will pass a 200-mesh screen, and is blown into the furnace with about 15-oz. air pressure. The coal used may vary in ash content from 6 to 7 per cent. up to as high as from 15 to 20 per cent., without giving trouble. The ratio of charge to fuel varies from 5 to 7½ : 1. The burners are inserted directly in the rear wall of the furnace, and several are used, from four to six being the usual number. The type of burner varies in each plant with apparently equally satisfactory results.

When using fuel-oil in the furnaces it is generally from 17 to 19 Bé., and is preheated to about 200° F. to 250° F. before burning, as this results in fuel economy. When as much heat as possible has been extracted from the gases, they are passed through waste-heat boilers for a further recovery. These are from 500 B.H.P. to 750 B.H.P., and are frequently connected to a common cross flue,

extending from all the reverberatory furnaces, so that in case of a shutdown of a furnace the boiler capacity will not be lost ; and if a boiler is down for cleaning or repair, the other boilers are available for the utilisation of the waste heat. It has been found advisable to have the flues from the furnaces to the boilers sloping slightly towards the furnaces, as otherwise trouble may be experienced from the accumulation of slag.

The reverberatory furnace is the most satisfactory apparatus in which to treat fine ores, but it usually requires an extensive roasting plant, occupies a large amount of space, and locks up a large amount of valuable metal. Hence the investment is large for a given tonnage.

LEACHING.

Copper has been extracted from its ores by heap-leaching methods in Spain since 1752, but these contain from 2 to 3 per cent. of metal. With modern methods it is economically possible to treat ores containing much smaller quantities of copper. In the spring of 1923 the Ohio Copper Company of Utah commenced the leaching of an ore which averages only 0·3 per cent. of copper. This has since proved to be a profitable undertaking. It consists of a copper-bearing quartzite, in which the copper minerals exist principally in the fissures. The quartzite is practically inert to chemical action, while the copper minerals are readily attacked by the leaching solution. At the Calumet and Hecla mine, an old tailing containing only 6 lb. of copper per ton (0·27 per cent.) has been successfully treated by an ammonia process. It has been estimated that about 15 per cent. of the copper output of the world is now produced by leaching, and two of the largest of such plants in operation at the present time produce copper at a considerably lower cost than by any other method of treatment. The leaching of copper and silver ores is now in a similar position to that of gold and silver cyanidation, and, especially in the case of copper ores, the process and plant used have followed very closely those employed for cyanide work. Since 1905, processes for the wet extraction of zinc and lead have been developed, and will probably in a few years become formidable rivals to smelting methods. Already the wet metallurgy of zinc is of considerable economic importance. Lead leaching at the moment has not attained so favourable a position as copper and zinc, and there is room for much further research in this direction.

REFINING.

Twenty years ago the manufacture of steel in the electric furnace was still in the embryonic stage. To-day more than 1200 such furnaces are in operation in Europe and America (including Canada), in about equal numbers in the two continents. In the decade 1910–20 the development of what may be called ' electric steel ' has been astonishing. It increased from 52,141 tons in 1910 to 502,152 tons in 1920. In 1925, 1,042,000 tons were produced, of which the U.S.A. was responsible for 615,000, Italy 129,000, Germany 127,000, France

68,000, and Great Britain 44,000. The principal use of such furnaces has been in producing alloy and tool-steel ingots and castings. The first advantage of the electric furnace is its flexibility ; the second consists in the method of applying the heat; and the third lies in the quality of the product. The outstanding disadvantage of the electric process is its cost. It may be expected that, with the continued improvement in efficiency of power-production plants, this disadvantage will tend to become less and less. Another factor which will operate in the same direction will be that economies in furnace operation will be more thoroughly understood and practised. Another disadvantage, from which the furnace has suffered more or less hitherto, is that it has been operated by men unfamiliar with its 'possibilities. To some extent the view has prevailed that electric steel occupies a field midway between acid and basic open-hearth steel and crucible steel. This is not the case. The quality of electric steel is fully equal to that of crucible steel, and can be achieved provided that refining is properly carried out metallurgically. If the electric steel is manufactured with care and the metallurgical treatment is correct, none of the five classes of non-metallic impurities (of which products from the reaction between dissolved and suspended oxides and gas and deoxidisers, and oxides not acted upon by deoxidisers, are the most important) ought to be present in more than small amounts. Except for small amounts of manganese sulphide and silicate, electric steel should, in fact, be free from non-metallic inclusions when melted with restricted or with no oxidation. Even when melted with complete oxidation, if it is deoxidised thoroughly it should still be cleaner than basic open-hearth steel.

Oberhoffer and Beutell[3] have shown that in a very large number of open-hearth steels the gas dissolved averaged from 13-130 c.c. per 100 grams of metal. The gas contained about 75 per cent. carbon monoxide, the rest being hydrogen, nitrogen, and a small amount of carbon dioxide. Steel metallurgists have paid far too little attention to the presence of gas in steel and to the effect on its quality, but it has been proved that the content nitrogen reduces the tensile strength, and still more the ductility. In the open-hearth process the atmosphere with which the metal is in contact contains oxygen, nitrogen, hydrogen, and carbon monoxide. In the electric process, on the other hand, the amounts of oxygen, hydrogen, and nitrogen should be very much less, and the only gas that should be present in any quantity is carbon monoxide. Even this will only occur in small amounts, as furnace gases containing oxygen are absent. Precise figures as to the amounts of gas actually present in electrically-made steel are, however, still lacking.

' PEARLITE ' CAST IRON.

One of the outstanding advances of the last twenty years has been the practical use of the

[3] *Stahl und Eisen*, 1919, vol. 39, pp. 1584-90.

equilibrium diagram in the scientific manufacture of industrial metals and alloys. So important has this aspect of metallurgy become that in 1920 a society was founded in the U.S.A. known as the American Society for Steel Treating, for the purpose of improving the scientific manufacture of metals. This society has to-day a membership of 3500.

High-carbon iron carbon alloys solidify 'white' unless a particular stimulus is present to cause the precipitation of graphite. They consist accordingly of cementite and pearlite. Since 'white' iron is so hard as to render it incapable of being machined, its use is greatly restricted in mechanical engineering work. The addition of silicon, however, causes the formation of free carbon from such a white iron, and it is possible in certain favourable conditions, including slow cooling, to produce a cast iron consisting only of silico-ferrite and foliated coarse graphite. Such a material is very weak, although soft, and apart from a few special cases, such iron is but little used for mechanical engineering work. Between these two limiting conditions come the usual technical kinds of grey iron. The microstructure depends on the smelting and casting processes used, the conditions of solidification and cooling after casting, and upon the chemical composition. The rate of cooling is, of course, considerably affected by the cross-sectional area of the particular casting. In the microstructure of ordinary grey iron are usually found together varying quantities of graphite, silico-ferrite, pearlite, free cementite, and the phosphide eutectic, with inclusions of iron and/or manganese sulphide.

A carbon steel containing 0·9 per cent of carbon consists, when annealed, of eutectoid pearlite only, the structure being uniform and dense. This material is pure steel. It has, as is well known, very remarkable mechanical properties. The problem of improving the qualities of cast-iron consists essentially in preparing a material composed mainly of pearlite with deposited graphite. A cast iron of this kind would certainly be superior in properties to any of the ordinary varieties, and it might be expected to exhibit mechanical properties approximating to those of pearlite steel, which would be influenced only by the graphite. Numerous tests carried out by different investigators on castings approximating to the above structure bear out this view. It was at first not found possible to get the desired structure in current practice. Diefenthaler and Sipp were, however, able to devise a process to enable this structure to be obtained regularly. It was patented in 1916. It has been improved upon, and has finally led to very definite rules for achieving the desired properties.

The properties found in the cast iron are: (1) High transverse and tensile strengths and toughness; (2) high resistance to impact stresses; (3) moderate hardness when properly treated; (4) only a slight tendency to the formation of 'pipes' and hence the possibility of making complicated castings; (5) great resistance to sliding friction (abrasion); and (6) fine and dense structure which is unaffected by temperature changes.

SORBITIC STEEL.

Steel wire ropes, after passing through the 'patenting process,' which consists in heating to a temperature at which steel scales, and then cooling more or less rapidly through the critical points, contain large quantities of 'sorbite' readily detected by the microscope after etching, or by the dark colour that the whole surface assumes when etched side by side with the rod before patenting. The property of enabling the patented rod to be drawn to a much greater fineness than is possible in the unpatented material is due to the effect of the sorbite present. Stead and Richards [4] concluded that if sorbite is responsible for the excellent qualities of oil-quenched steel and negatively quenched steel wire rods, there is no reason why it should not be produced in steel rails, tires, etc., without great expense. With this object in view they experimented on 5-foot lengths, subjecting them to a variety of treatment.

Although the results of these experiments were decidedly promising, they were not able satisfactorily to treat a normal 30-foot length of rail. In all cases the distortion of the longer lengths was so considerable that their process never became a commercial success. The practical problem of treating the full lengths satisfactorily has been solved by Messrs. Sandberg so as to produce sorbitic structure. They realised that the right temper in the rail could be obtained in the course of one single operation if the correct rate of cooling through the critical range of temperature was secured. The precise range depends upon the composition of the steel. Their experiments using air-cooling were so encouraging that they were soon able to treat full-length rails of heavy section. The results obtained made it perfectly clear that their process could be carried out without interfering in any way with the output of the rail mills and at a comparatively low expenditure. The first rails treated were tramway rails, and gaugings taken from these after they had been one year in the track under very severe traffic showed that their life would be about 100 per cent. longer than that of the Sandberg high silicon rails of the same composition but untreated and laid at the same time in the same track. Plants for the Sandberg treatment of rails were put down by the Bethlehem Steel Company at their Sparrow Point Works, where trials were carried out and excellent results obtained. Shortly afterwards another plant was put down at the Dowlais Works of Messrs. Guest, Keen and Nettlefold, while a number of trial orders have been carried out on rails for various home railways.

The tensile strength of rails has frequently been raised from about 55 tons per square inch untreated to 65 and 70 tons per square inch after treatment, and even higher, without showing any signs of brittleness. Treated rails have, in fact, stood up to twice and even three times their specified falling weight test without breaking. The Brinell tests also clearly show that the process does not merely

[4] *Journal of the Iron and Steel Institute*, 1903.

give a surface hardening, but that the treatment effect is produced throughout the head. The increased resistance to shock is due to the peculiar fineness of the structure of sorbite, which also gives smaller surface particles for tearing away by abrasion, and thus greatly reduces the wear in service. From careful observation under severe traffic conditions it has been found that treated rails have given double the life of untreated rails, and in some cases even better results have been obtained.

HIGH-SPEED TOOL STEELS.[5]

The revolutionary feature wherein tools made of these steels differ and exceed in service the tools formerly used, is their ability to maintain a sharp, strong cutting edge while heated to a temperature far above that which would at once destroy the cutting ability of a simple steel tool. A high-speed tool can be made to cut continuously at speeds from three to five times as great as that practicable with other tools and even when, as the result of the friction of the chip on the tool, it may be red hot at the point on top where the chip rubs hardest, and the chip itself may, by its friction on the tool and the internal work done on it by upsetting it, be heated to a blue heat of about 300° C. or even hotter. Accordingly these tools have in the past twenty years worked a remarkable revolution in the machine - shop business of the whole world, affording largely increased outputs and commensurately lower costs. As a consequence they are now used very generally, and in some shops almost exclusively, for machining iron and steel as well as some other metals by cutting operations by machine tools.

The property of red hardness, or ability to retain hardness at a red heat, may be imparted to steels of suitable composition containing chromium, tungsten and vanadium and, in the most recent tools, cobalt as well, by a unique heat treatment to which they are subjected. This is the Taylor-White process [6] introduced at the works of the Bethlehem Steel Company in 1899. Tools thus treated were shown at the Paris Exhibition in 1900.

In the early days, after a good deal of experiment, the composition settled down to a basic one of about 14 per cent. of tungsten with from 3 to 4 per cent. of chromium. The next step was to introduce still greater percentages of tungsten and also to add vanadium. A class of steel has now been on the market for some time containing about 18 per cent. of tungsten, 4 per cent. of chromium, and anything up to 2 per cent. of vanadium. This class appears to have justified itself as indicated by the wide demand for it. The latest development came comparatively recently with the addition of cobalt (from 2 to 6 per cent.). These steels have also taken their place and found a market. In some steels molybdenum is added as well as the above four alloy elements.

The cutting edge of a rapid tool at work is prob-

ably never so hot as the metal which is behind it, where the heating caused by the friction of the chip as it is deflected and rubs hard on the tool is most intense. The edge itself is kept relatively cool by the cold metal flowing upon it. It is not generally realised that the point of the tool does not cut, and that it only drives open the crack which advances in front of it. A high-speed tool fails through the turning, which impinges on the top face of the tool, wearing away the steel until the cutting edge is actually broken off.

MUMETAL.[7]

The first commercial application of high-frequency melting in Europe was made by a British firm for the preparation of nickel-iron alloys for submarine cables. The research work pursued in order to find a suitable alloy was thereby much facilitated, and quickly resulted in the perfection of the series of alloys known under the name of 'mumetal' (so called because the Greek letter μ is used as the symbol of permeability). These alloys have highly desirable characteristics, and by their use the speed of cabling can be increased seven to eightfold.

A typical mumetal alloy has the following composition :

Nickel .	.	.	.	74·0 per cent.
Iron	.	.	.	20·0 ,,
Copper	.	.	.	5·3 ,,
Manganese	.	.	.	0·7 ,,

An alloy of this composition has a magnetic permeability of 7000. Low hysteresis loss with a very high permeability at low magnetising forces are the characteristics chiefly required in these metals.

The composition of the mumetal may be varied according to the type of cable which it is proposed to use, and the annealing may be adjusted to give either (a) maximum neutral permeability, (b) maximum permeability at magnetic saturation, or (c) high or low fields for magnetic saturation.

The range of alloys developed for this class of work contains from 75 per cent. to about 50 per cent. of nickel, with percentages of iron varying from 20 to 25, and certain quantities of copper and manganese, but in every case freedom from carbon is one of the primary essentials, and for this reason the high-frequency furnace has proved the only suitable melting equipment.

In certain types of cable an increase in electrical resistance of the alloys is desirable, and in this case an extra element, which may be tungsten, chromium, silicon, vanadium, titanium, molybdenum, or aluminium, may be added in small quantities.

ANTI-CORROSION METHODS.

Aluminium is ordinarily covered with a protective film of oxide or hydroxide. It does not, however, constitute a perfect protection in the presence of corrosive liquids and even neutral salt solutions. It tends to crack and lose its power of adhesion

[5] Hibbard, " Manufacture and Uses of Alloy Steels."
[6] Taylor, F. W., " On the Art of Cutting Tools," *Trans. Am. Soc. Mech. Eng.*, vol. 28 (1908), pp. 31-350.

[7] Campbell, *Journal of the Iron and Steel Institute*, vol. 112, p. 74.

to the metallic surface. Local corrosion (pitting) then sets in. Moreover, this film is much more liable to crack when subjected to alternate wetting and drying, particularly at an air-liquid interface. Probably the interfacial tensions of metal, air, and water operate in producing this result. The practical problem therefore consists in finding a method of forming a strong and tightly adherent film of oxide or hydroxide instead of the thin film. Mott [8] showed that such a hydroxide film could be formed by making the metal the anode in a bath of sodium hydrogen phosphate, and recommended this treatment as a protection against corrosion. Working for the Corrosion Research Committee of the Institute of Metals, and with the aid of financial assistance from the Department of Scientific and Industrial Research, Dr. Bengough and Mr. J. M. Stuart, during the years 1921–24, carried out a series of investigations starting from this point, and found that the film produced by ' anodic oxidation ' in a bath containing a chromate, bichromate or, best of all, chromic acid, protects the metal much more effectively against corrosion.

The process is carried out as follows : " After

[8] Mott, " Electrochemical Industry," 1904, 2, p. 129.

thoroughly cleaning the surface of the aluminium or its alloy, it is immersed in a suitable bath, *e.g.* dilute chromic acid, along with a carbon rod ; a small external electromotive force is applied so as to make the aluminium the anode and the carbon the cathode. The applied electromotive force is gradually raised to a value depending on the nature of the alloy and on the composition of the bath. Thus with duralumin in a chromic bath the voltage may be safely raised to 50 volts. After treating for some time in this manner, the surface of the metal becomes covered with a semi-opaque uniform white coating. This seems to consist almost entirely of aluminium hydroxide in a glassy adherent form. The hydroxide is possibly hydrated to some extent, but the hydration cannot be much, since the coating can be heated to at least 350° C. without changing in appearance or density."

The laboratory investigations were followed by successful experiments on a larger scale at the Royal Aircraft Establishment at Farnborough, by agreement with the Air Ministry, and the process, which is protected by patent, is now being worked in Great Britain by several firms on non-exclusive licences from the Department of Scientific and Industrial Research.

Organography of Plants.[1]

A ' FESTSCHRIFT ' celebrating the seventieth birthday of Dr. Karl von Goebel, professor of botany in the University of Munich, was published in 1925 as a special volume of *Flora*. It was initiated by an international committee including many of his colleagues, pupils, and friends : it comprises thirty-eight memoirs on the most varied botanical topics, and these themselves bear witness to the catholicity of the interests of the veteran whose birthday they celebrate. His election in 1926 as a foreign member of the Royal Society has marked the recognition in Great Britain of his great scientific career, happily by no means ended, though it has reached the prescribed span of life. These events followed closely upon the completion of the second and greatly enlarged edition of his " Organographie der Pflanzen." The interest which they have aroused among botanists is readily understood, for the name of von Goebel is intimately associated with an essential change of scientific outlook upon the organisation of plants. This has lately been made more than ever apparent in a volume from his own pen, written in celebration of the centenary of the birth of his teacher, Hofmeister, a translation of which into English was lately published by the Ray Society, and reviewed in NATURE (Oct. 2, 1926, p. 473). This essay reveals with a truly philosophic touch the genius of the master, while it serves also as a natural guide to any appre-

ciation of the life-work of the pupil, von Goebel himself.

In the early part of the nineteenth century a stiff and artificial nature-philosophy was still dominant. This was clearly incompatible with those evolutionary views which were then forming themselves in men's minds. Even before " The Origin of Species " was published, a change of outlook had been initiated. Hofmeister's keen insight had tracked down, and his pencil had recorded in detail, facts relating to Archegoniate plants, which more than any others were at that time essential for any consecutive evolutionary scheme for the plant kingdom as a whole. These facts were stated by Hofmeister with a breadth of view which allowed of their ready application later in terms of adaptation to environment. He was not merely an observer of stark structure, but he broached the subject of causal morphology, a branch of study then only nascent, but great with the promise of the future.

It has been the happy lot of von Goebel as his pupil to carry on the torch which Hofmeister had thus placed in his hands, and to deliver it with ever-increasing glow to a later generation. Morphology in his hands has taken a more rational place than was possible before. Under the title of " Organography,"—a word already used by Sachs in 1882, from whom also von Goebel will have drawn stimulus and guidance in the years of his assistantship in Würzburg—he has embodied in two stately volumes a wealth of fact treated comparatively, experimentally and developmentally, and related throughout to function. While maintaining the Hofmeisterian tradition of exactitude, he has promoted the living aspect already so

[1] 1. " Organographie der Pflanzen," Dr. K. Goebel. Zweite Auflage. (Jena : Fischer, 1913–1923.)
2. " Die Entfaltungsbewegungen der Pflanzen." Ergänzungsband zur Organographie der Pflanzen. (Jena : Fischer, 1924.)
3. " Festschrift zum siebzigsten Geburtstage von Karl von Goebel, in München." (Jena : Fischer, 1925.)
4. " Morphologische und biologische Studien." Von Prof. Dr. K. von Goebel. *Ann. Jard. Bot. de Buitenzorg*, 36. (Leyden, 1926.)