the comparatively shallow water over the Longitudinal Ridge. Next, that part of the current which is first to cross the ridge is sharply deflected to the left when (and because) it reaches the deep water on the eastern side, and so it shapes its course northward towards the Porcupine Bank and the seas beyond; while the other and lesser portion of the great current is slewed more and more to the right as it follows the shallow waters towards the Azores. Passing Madeira and approaching the Portuguese coast, the course of the current becomes extremely complicated; and "it stands to reason" (as our authors say) that it is here closely following, in all its constant twists and turns, the ups and downs of the complicated topography of the bottom.

Heterogeneity of Steel Ingots.

WHEN a mass of molten steel, originally of uniform composition, solidifies, the analysis of the resulting ingot shows variations from point to point due to local segregations of the various constituents. The extent of this variation differs widely in different cases, and certainly increases with poor steel-making technique. Even with the best of conditions, however, segregation inevitably occurs, and the Iron and Steel Institute appointed in 1924 an important committee to investigate this point and to discover, amongst other things, to what extent segregation must be considered to be inevitable even with the very best steel-making practice.

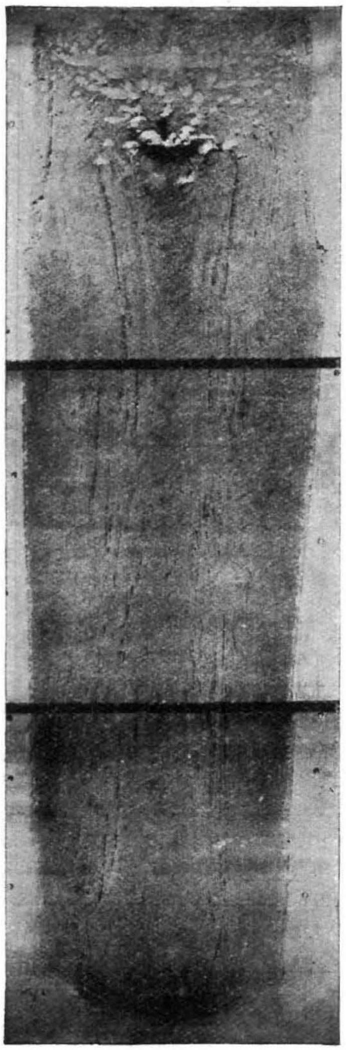


FIG. 1.—Sulphur print of an ingot of nickel-chromium steel showing Λ- and V-shaped segregations. From the Second Report to the Iron and Steel Institute of the Committee on the Heterogeneity of Steel Ingots.

The first report of this Committee was published in the *Journal of the Iron and Steel Institute*, vol. 113, in 1926, and dealt in an exceedingly able manner with segregation in plain carbon steels which were free from blow-holes. It was shown that the ingot could be divided up into zones purer than the average, and others in which definite segregation was to be detected. The lower part of the ingot, for example, is relatively very pure, and a region, shaped something like a sugar-loaf, extends upwards from the base along the central axis. Outside this are found a series of segregated zones of Λ shape separating the steel in the centre from another purer region under the skin. The most highly segregated field occurs at the top of the ingot just below the cavity in the feederhead, and from this the Λ segregates descend somewhat as do the fangs from a tooth. Finally, there is a series of V-shaped segregates extending down the axis of the ingot which may be connected with similarly shaped and situated flaws, due to contraction in the solid state. Fig. 1, which represents the sulphur print of an ingot of a nickel-chromium steel weighing 49 tons, shows these segregations clearly.

In a second report, recently published, the whole question is carried much further, and again comprises an account of some extremely careful work. It considers, first, segregation in sound alloy steels, and, secondly, segregation in ingots of carbon steel which had been deliberately produced highly charged with gas. This, on the solidification of the metal, had been liberated in part and produced blow-holes.

Dealing in the first place with the alloy steels of the nickel, nickel-chrome, and nickel-chrome-molybdenum types, ingots from 15 cwt. to nearly 120 tons have been examined and, generally speaking, the results obtained are closely similar to those given by the plain carbon steels. It is shown again that the degree of segregation normally increases as the size of the ingot increases. Nickel, although it does itself segregate, does so only to a minor degree, and in, for example, an ingot weighing roughly 3 tons, the nickel content in the highest analysis was 3·16 per cent, and in the lowest 3·05 per cent. There is also some reason to believe that the presence of this element has an influence in decreasing the extent of segregation of other elements, and taking, for example, a nickel and a plain carbon steel ingot of roughly similar size, the figures given below may be cited.

Element.	Nickel Steel Ingot.			Carbon Steel Ingot.		
	Highest (per cent).	Lowest (per cent).	Range (per cent).	Highest (per cent).	Lowest (per cent).	Range[1] (per cent).
Carbon	0·32	0·28	13	0·43	0·32	32
Sulphur	0·049	0·024	59	0·047	0·032	37
Phosphorus	0·032	0·022	29	0·055	0·039	37
Nickel	3·16	3·05	3·5	nil	nil	..

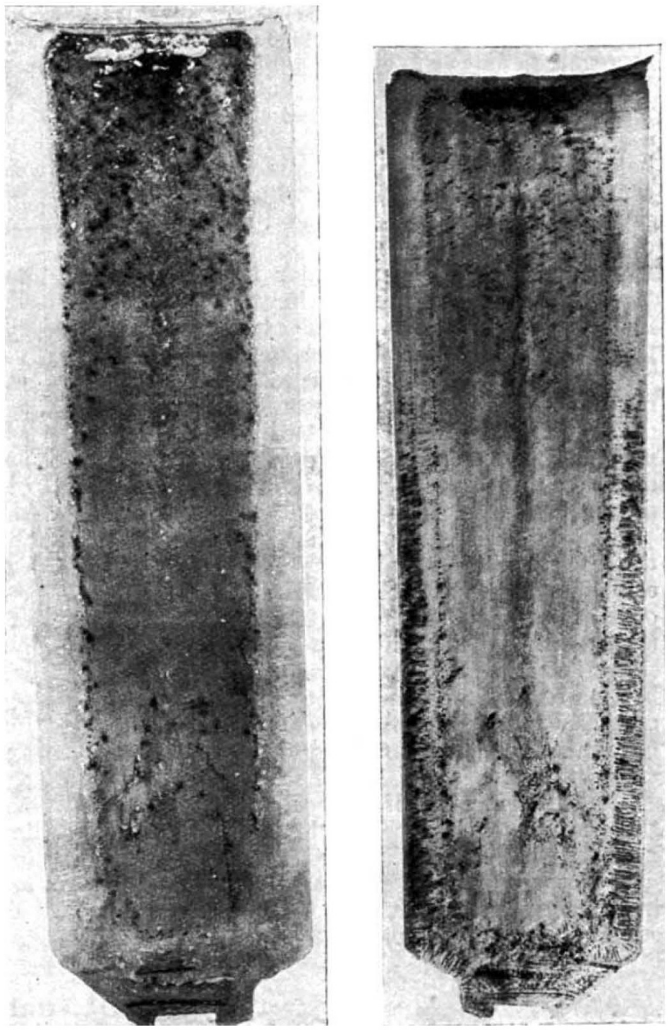
[1] Calculated on mean composition of ingot.

Although there is a slightly greater segregation of sulphur, in the nickel steel ingot the segregation of both carbon and phosphorus is reduced.

A point of very considerable interest is raised as a result of analyses which have been made on two similar ingots of a nickel-chrome steel weighing 2 tons 4 cwt. each. These ingots were prepared from the same electric furnace heat and differ only in the temperature at which they were cast and the speed of pouring. Ingot *B* was cast at an average temperature of 1590° C., and *D* was poured at 1550° C. The time of pouring of *B* was 3 min. 40 sec., while *D* was poured very much more rapidly in 2 min. 10 sec. The amount of segregation in ingot *B* was very distinctly less than that of the other ingot *D*. Expressing the maximum degree of segregation as the percentage difference of the maximum and minimum figures when compared with the average for the whole ingot, this range was for carbon 14 per cent in the case of ingot *B* and 24 per cent in the case of *D*. Manganese, which segregates only to a minor extent, showed no difference in the two ingots, the range being 7 per cent for each. In the case of silicon the range was 7 per cent for ingot *B* against 15 per cent for ingot *D*. The same phenomenon is shown for sulphur, phosphorus (where it is particularly marked), nickel, and chromium: the sulphur figures being 12 per cent and 25 per cent: phosphorus 7 per cent and 33 per cent: nickel 2 per cent and 3·5 per cent: and chromium 3 per cent and 4 per cent.

Another case of very considerable interest from the point of view of armament and special engineering material was a 119-ton ingot of nickel-chrome-molybdenum steel. Compared with a plain carbon ingot of similar dimensions, it is shown that the segregation of carbon, sulphur, and phosphorus has not been materially affected by the alloying elements in this size of ingot. Segregation of all three special elements is observed, nickel to a minor extent, the maximum variation being only about 5 per cent of the mean analysis; chromium to a considerable degree, about 30 per cent, and molybdenum to a very marked extent, giving a range of composition of 70 per cent. The regions in which these special elements segregate are roughly the same as those selected by the elements in the plain carbon steels.

The report then passes on to the consideration of heterogeneity in steel ingots which had not been 'killed,' that is to say, which were made from steel supersaturated with gas. The Committee points out that such ingots are representative of the great tonnage of steel produced for the manufacture of plates, sections, and other general purposes. Such ingots are chiefly characterised by the facts that the steels have low carbon and silicon contents and are cast in moulds which are not provided with feeder-heads. During the freezing of the liquid steel, there is a liberation of gas which results in the production of blow-holes in certain zones of the ingot, and it is the influence of this factor in modifying the degree and form of the heterogeneity to be found which has been considered. Owing to the volume of the blow-holes, the 'pipe' or central shrinkage cavity of the 'killed' ingot does not occur, and the fact that the small blow-holes in this class of material may weld up during the rolling process causes a much higher yield of marketable material to be produced. In the case of steel required to withstand the most severe conditions of surface, the greatest precautions must be taken to reduce the gas content to a minimum, but it is neither necessary, nor economically practicable, to carry out the degasification to this degree in steel for the more common purposes. In fact, it is sometimes found to be actually desirable, in order to produce certain qualities in the finished product, to cast the steel while it is highly charged with gas.



(a) (b)

FIG. 2.—Ingot of non-piping steel. (*a*) Sulphur print; (*b*) macro-etching. From the Second Report to the Iron and Steel Institute of the Committee on the Heterogeneity of Steel Ingots.

As an example of one of the more extreme cases may be quoted an ingot of steel intended for the production of weldless tubes by the Pilger process. This ingot, weighing just above 3 tons, was made by the basic Siemens process and was of the following average composition: Carbon, 0·064; manganese, 0·35; silicon, 0·012; sulphur, 0·039; phosphorus, 0·010 per cent. The sulphur print and the macro-etched structure are shown in Fig. 2 (*a*) and (*b*). It will be seen that four zones may be distinguished. There is, first, a thin solid outer skin about ½ an inch thick. Within this there is a zone about 4 inches thick free from segregation but containing numerous elongated blow-holes, especially in the bottom half of the ingot. Zone 3 consists of a thin envelope of highly segregated material containing numerous blow-holes of globular form. Finally, there is the central portion of the ingot, which appears to be more impure than zone 2, and the upper portion of which contains blow-holes both with and without segregates. There is no major pipe cavity, but there are shrinkage cavities in the centre of the ingot and traces of the V type of segregation. In the lower half of the central zone a particularly unsound area containing segregated regions of rather peculiar form is to be seen. An explanation of this unsoundness of the bottom of this ingot has not yet been found, but it is possible that the condition of the bottom plates on which the ingot mould had rested played some part in it.

Except in the case of silicon, the magnitude of the segregation phenomenon for the various elements in these steels containing blow-holes is of the same order as is found in the 'killed' piping steels. In the tube ingot a high value for the silicon content, however, was detected near the bottom of the ingot, but whether this would occur normally is still uncertain, since, as has already been mentioned, the condition of the bottom plates may have had some influence. Concerning the general distribution of the elements there is in these ingots, as in those made from piping steels, a concentration of the impurities (excepting silicon) in the upper parts of the ingot, though there is little indication of the negative segregation of carbon, sulphur, and phosphorus in the lower central region.

All the ingots show evidence of an increased silicon content in the lower middle portion to an even more marked degree than do the ingots of the 'piping' type dealt with in the first report. The ingots, further, contain V segregates near the central axis, though these are not so distinct as they are in the piping steels. The tube steel did not show the Λ segregate, though in the case of 'semi-killed' ingots this is again found, confined, however, in general, to a very narrow zone, except in the case of two ingots which had been cast at a low temperature. A distinctly interesting observation was made in connexion with an ingot weighing 3 tons 6 cwt. of a 'free-cutting' steel produced by the basic open-hearth process. The composition of this material was carbon 0·12, manganese 0·66, silicon 0·03, sulphur 0·113, and phosphorus 0·098 per cent respectively. Although the silicon content is very low and no additions of aluminium were made, the ingot showed the typical structure and features of ingots of 'killed' steel. The liberation of gases which is typical of low silicon, 'unkilled' steel has in this case been prevented by the high content of sulphur, an element which evidently acts as a powerful deoxidising agent.

The present report concludes with interim statements of work which is being done in the University of Sheffield on changes of the density of steel in the neighbourhood of the melting point and the viscosity of molten steel, and also researches being carried out at the Royal Technical College, Glasgow, on the freezing and melting ranges of the steels dealt with in the two reports and on the sulphides present in these steels. The amount of work which has been carried out for the purpose of these reports by the steel-making firms and metallurgical institutions of Great Britain is extremely great, and the value of the work when it is complete, both to the manufacturer of steel and to the user, cannot be over-estimated. As an example of a scientific investigation of a point of practical metallurgical importance, it would be difficult to call to mind any previous piece of work of this magnitude carried out with anything like the care and industry which has been shown in the present case. F. C. T.

Obituary.

PROF. E. M. CROOKSHANK.

THE sudden death of Prof. Crookshank on July 1 removes one who was a pioneer of bacteriology in Great Britain. He came of a family of soldiers, but at an early age showed a liking for scientific work, and after school days was first a pupil of Sir Ray Lankester at University College, whose teaching doubtless influenced his choice of career. Obtaining a science exhibition at King's College, London, he entered there as a medical student, and finally graduated as M.B. with honours in the University of London. During his training at King's College, Lister arrived in London to become surgeon to King's College Hospital, and Crookshank was one of his dressers and afterwards house surgeon at the Hospital. He thus early became imbued with the teaching of Lister and acquainted with the germ theory of disease. In consequence of his experience under Lister he was selected for special duty in the Egyptian Expedition of 1882, was present at the battle of Tel-el-Kebir, and received the medal and Khedive's star for his services. He wrote a report on the antiseptic methods employed in the campaign and gave valuable evidence before the Royal Commission on Medical Services in Egypt.

Following this, Crookshank decided to take up bacteriology as a career, and proceeded to study in Paris under Pasteur, and afterwards in Berlin under Robert Koch. Returning to London, he published in 1886 his "Manual of Bacteriology," which passed through four editions, was translated into French, and was the standard text-book of bacteriology at