

were finished, only from 1.25 to 2.5 per cent. of them were so defective as to be classed as second quality.

According to a communication by M. A. L. Colby,* neither a propeller shaft with .565 per cent. Copper nor a gun tube with .553 per cent. showed any defects after forging and hardening, and armour plates with .575 per cent. flanged well and answered all the requirements of the American Navy. Various samples of Bessemer steel, with Carbon ranging from .11 to .65 per cent. and with .292 to .486 per cent. Copper, showed no red shortness on rolling. His experience also tended to show that Copper had but little tendency to liquate.

Messrs. Stead and Evans † have carried out a valuable series of experiments on the influence of Copper on steel rails and plates, partly with a view to break down the prejudice with which engineers have been wont to regard Copper in steel. Ladles of steel were divided into two parts, to one of which Copper was added, and ingots from both were then cast, rolled, and subjected to similar tests. The Copper added ranged from .5 to 2 per cent. In each case the steel containing Copper rolled equally as well as that without, except in the case of the 2 per cent. sample, which was afterwards found to be overheated. The authors conclude that a steel containing a high percentage of Copper, although not red short in the ordinary sense, yet will not bear the same amount of heat as the same metal without Copper, thus showing that the effect of the latter resembles that of Carbon rather than that of Sulphur.

The cupreous samples showed a slightly increased tensile strength, a somewhat higher elastic limit, and less elongation, and (with one exception) less contraction of area. They stood percussive tests as well as the normal metal, and the bending tests and welding tests showed no difference. The investigators conclude that Copper does not possess the property of making steel red short.

Experiments by Muller ‡ and Dillner § confirm the results obtained by other investigators as to the non-injurious effect of Copper on the physical properties of steel. Up to .62 per cent. it somewhat increases elasticity, strength, and hardness, without appreciably affecting the elongation, and no red shortness is observable during rolling or forging. In the case of harder steels containing .5 per cent. of Carbon the toughness of the metal is diminished, and on quenching in water the steel showed considerable brittleness.

Messrs. Stead and Wigham || have also investigated the influence of Copper on steel wire. The Copper in the steels experimented with varied from .46 to 2 per cent. The conclusion arrived at, from an examination of the mechanical properties of these steels, was that Copper in such large quantities did not improve the quality of the wire, but generally had a deteriorating influence, particularly in the presence of high Carbon. The only apparent useful property the cupreous steel wire seemed to possess was that it was not so readily corroded as the non-cupreous material.

In a separate communication on the alloys of Copper and iron, Mr. Stead ¶ shows that, on melting with Charcoal, alloys containing more than 7.5 per cent. Copper, Copper containing about 3 per cent. of iron is thrown out of solution and falls to the bottom, leaving a layer of carburised iron on the surface containing about 7.5 per cent. Copper. This action of Carbon, in

* *Stahl und Eisen*, 1900, pp. 20, 55.

† *Iron and Steel Inst. Journ.*, 1901, vol. i., p. 89.

‡ *Stahl und Eisen*, vol. xxvi., p. 1444-1447.

|| *Iron and Steel Inst. Journ.*, 1901, vol. ii., p. 122.

§ *Ibid.*, vol. xxvi., pp. 1493-1495.

¶ *Ibid.*, 1901, vol. ii., p. 104.

throwing Copper out of solution, probably accounts for some of the conflicting results obtained with iron alloys of this metal.

C. F. Burgess and J. Aston* have also examined the properties of iron-copper alloys, and found that the alloys up to 2 per cent. Copper forge well at red heats. Those from 2 to 7 per cent. Copper will not forge at a low temperature, and rather poorly at a white heat, the ease of workability varying inversely as the percentage of copper. The same authors,† on examining the magnetic and electrical properties of these alloys, found that above 2 per cent. Copper the permeability falls off rather rapidly as the Copper content is increased, but only bars of 4 per cent. and more are conspicuously poor. Annealing greatly improves the quality of the bars. The authors consider that there is nothing to be feared from the effect on the magnetic properties of the small quantities of Copper ordinarily found in commercial steels. The electrical resistance is found to increase to a maximum at a Copper content of 1.51 per cent.

The Influence of Other Elements.

Antimony.—As might be expected from the physical properties of Antimony, its presence in steel seems to be highly detrimental. No very recent information, however, appears to be available. It is said to make iron both red and cold short, even when present in very minute quantities. It is seldom present in iron ores, and when added to steel largely passes out again at the melting point of steel.

Bismuth.—Bismuth appears to act very much like Antimony, and to have nearly as detrimental effects on the properties of the steel into which it is introduced.

Calcium.—Although the influence of Calcium on steel is unknown, it is interesting to note that, according to some recent investigations of Mr. G. Watson Gray, Calcium is often present in high-grade Ferro-Silicon made in the electric furnace. We quote some partial analyses from samples of this material:—

TABLE LXXI.

	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Silicon,	31.90	44.05	56.70	62.90	68.65	78.80
Iron,	61.30	45.28	26.70	24.40	9.91	12.64
Manganese,	3.92	3.51	2.40	1.10	0.20	0.30
Aluminium,	0.22	0.47	3.52	1.52	2.40	4.76
Calcium,	0.79	3.29	7.12	6.96	14.40	2.32
Magnesium,	0.26	0.44	0.38	0.32	0.31	0.22
Carbon,	0.50	0.52	0.63	0.33	1.03	0.55

Tin.—Tin will alloy with iron in all proportions, but, for engineering purposes, the alloys are of no practical importance. Iron or steel sheets coated with Tin form the well-known *tinplate*, an article of immense importance in commerce. Generally, it may be said that the presence of small percentages of Tin is detrimental to iron, and, on the other hand, the presence of a small percentage of iron in Tin is detrimental to the Tin.

* *Electrochemical and Metallurgical Industry*, 1909, vol. vii., pp. 527-529.

† *Ibid.*, 1910, vol. viii., pp. 23-26.

Some recent experiments on the addition of small amounts of Tin to iron have been published.* Samples of iron containing from .1 to .63 per cent. of Tin were prepared and tested. It was found that all the samples forged well, though they were somewhat hard; all the samples rolled, but split somewhat at the edges; they welded well, except the one with the highest percentage of Tin (.63 per cent.); the bending tests, both hot and cold, were satisfactory. The Tin was found to be irregularly distributed in the ingots. Samples of crucible steel were also prepared containing .23, .5, .68, and 1.62 per cent. of Tin. All these samples forged well, except the last, which was somewhat red short; none of them, however, would weld.

In a charge of basic open hearth steel, into which Tin had been accidentally introduced, Zuger found .55 per cent. Tin, .015 per cent. Antimony, .03 per cent. Arsenic, and .182 per cent. Copper. This metal was found to roll quite satisfactorily into plates; on further rolling into sheets, however, cracks developed at the edges. Bars rolled from the metal bent close under the cold bending test, and gave a tensile strength of 40 kilos. per sq. mm., with an extension of 31 to 34 per cent. on 7.5 cm. From these experiments it would appear that Tin above .5 per cent. materially affects the welding properties of steel, but does not affect the tensile or extension tests.

Guillet† states that on the addition of Tin to steel, small quantities dissolve in the iron. When 5 to 7 per cent. is present a stannide is formed, which occurs in the shape of needles. It confers great brittleness, which renders the steel unworkable when present to over 10 per cent.

Zinc.—The effect of Zinc on the mechanical properties of steel is of no practical importance, and the only useful application of the alloys of iron and Zinc is in ordinary galvanising of sheets and other articles of commerce. In such articles there is a superficial alloying of Zinc with the steel or iron used. Alloys of iron and Zinc, containing about 10 per cent. of iron, are formed during the galvanising process in the Zinc pots, and are known as hard spelter, but on account of the easy volatility and the feeble affinity of the two metals, the greater part of the Zinc is removed on heating such alloys to a white heat. When Zinc is added to molten steel only minute traces of it remain in the metal, but if a rod of steel is immersed in a bath of Zinc, at high temperature, the steel is attacked with the formation of an alloy. This action is greater on high Carbon steel than on low Carbon steel, and recently Messrs. John Lysaght & Co. tried some experiments by immersing steel bars containing respectively 1.0 per cent., 0.5 per cent., and 0.1 per cent. of Carbon in the same Zinc bath, with the result that the bars containing 1.0 per cent. after a week were found to have entirely disappeared, those containing 0.5 per cent. had wasted to about one-half their original size, while the bars containing 0.1 per cent. were practically unattacked. Under certain conditions, however, mild steel is very seriously attacked by Zinc, and the author is aware of one case in which a galvanising pot made of mild steel plates was practically destroyed in twenty-four hours due to overheating.

Segregation.

In considering the influence of the various impurities on the mechanical properties of steel, the unequal distribution of such impurities is of the greatest importance. This is one of those matters which steel makers often find it convenient to ignore, but it is so well known and generally recognised

* *Stahl und Eisen*, vol. xxi, p. 330.

† *Iron and Steel Inst. Journ.*, 1906, vol. ii.

that it is necessary to face the facts, and to carefully consider the conditions which favour the segregation of impurities from the mass of the metal, and their concentration in different parts of the ingot. It is also an important point to be considered by engineers in drafting specifications, both in their own interests and in fairness to manufacturers, as even in the highest quality of steel, made with the greatest care, there will always be some slight variation in the composition of the material between the centre and the outside of the ingot, and, if reasonable allowance is not made for this, it may lead to rejection and cause considerable trouble to all concerned.

In the gradual cooling of large masses of impure metal and metallic alloys, there is always a tendency for certain constituents to separate or segregate and concentrate in certain portions of the mass, and this has a most important bearing on the homogeneity of steel ingots. This matter, in relation to steel, was first investigated by Stubbs* and Snelus† in 1881, and since then has received considerable attention from both practical and scientific men. Steel may be regarded as a complex alloy in which the impurities present, such as Silicides, Phosphides, Carbides, Sulphides, etc., are dissolved in the iron. These different bodies will vary in their freezing or solidifying points, some remaining fluid much longer than others, and all having a lower freezing point than the metallic iron, and eutectics are also formed with various impurities which have still lower freezing points. Consequently, those having the lowest melting point will tend to gradually segregate from the iron and concentrate in the hottest part of the ingot, which will naturally be towards the centre, as the ingot is rapidly being cooled from the outside by contact with the cast-iron mould. This tendency is modified by various forces, some acting with and some against it, and will be largely affected by the initial temperature of the molten mass, rapidity of cooling, etc. *Other things being equal*, the more rapid the cooling, the less the segregation, and, as rapidity of cooling will largely depend upon the size of the ingot, the smaller the ingot the less segregation there will be.

Professor Howe‡ divides bodies which tend to separate or segregate into three groups:—

- “1. Compounds which differ much in fusibility from the rest of the mass.
- “2. Compounds whose components have a strong affinity for each other, and which hence tend strongly to form during cooling.
- “3. Compounds which differ greatly in density from the rest of the mass.”

The proportion in which the segregating body is present will largely affect the result: the higher the impurities in the steel ingots the greater the segregation. Carbon and Phosphorus having a greater affinity than Manganese for iron, and the Carbides, Phosphides, and Sulphides of iron being more fusible and of lower density than the alloys of iron and Manganese, the former should segregate more readily than the Manganese, but the segregation of the latter is favoured by its being present in much larger proportion. There is no doubt that the Manganese also combines with the Sulphur and Carbon, and so segregates to some extent as Sulphide and Carbide.

It is generally found that segregation of one impurity means, more or less, the segregation of all, although this is not always the case. From a large number of results given by Professor Howe, it would appear that Carbon

* *Iron and Steel Inst. Journ.*, 1881, vol. i, p. 199.

† *Ibid.*, vol. ii, p. 379.

‡ Howe, *Metallurgy of Steel*, p. 205.

is the element which segregates most readily, but this is probably largely due to its generally being present in much larger proportion than other constituents, except Manganese. In the author's experience, Sulphur and Phosphorus are the elements which are generally found most unequally distributed, especially when the steel contains a somewhat high percentage of these. When there is any appreciable segregation of Manganese, Sulphur is generally found, and it is probable they liquate together as Sulphide of Manganese.

The rapid cooling of the outside of an ingot prevents any separation of impurities occurring there, but the centre of the ingot remaining fluid for a considerable time, the segregated matter travels inwards, assisted somewhat by the contraction of the metal. The impurities, being specifically lighter than the iron, tend at the same time to rise to the top of the ingot.

Numerous analyses of drillings taken from different parts of steel ingots have shown that the centre and top of the ingot always contain the larger proportion of impurities, and this somewhat fortunate concentration in a particular part of the ingot enables the steelmaker to remove this impure portion during manufacture much more readily than he could do if the impurities were irregularly distributed through the entire ingot. Thus in rolling rails and various sections, the top end of the ingot can be removed by shearing, and in special cases, such as the manufacture of guns or for other exceptional purposes, the centre of the ingot can be bored out. So important is it considered not to interfere in any way with this natural concentration of the impurities, that many American engineers specify in their rail and other specifications that the ingots are to be conveyed from the casting pit, and reheated in the vertical position, to assist the segregation of the impurities towards the top of the ingot.

From a very large number of analyses collected and tabulated by Professor Howe,* it is shown that it is by no means unusual in bad cases of segregation to find a difference of 50 per cent. or more in the impurities in different parts of the same steel ingot or finished section. This applies equally to rails, bars, plates, etc. Such examples of segregation are, however, abnormal, and usually occur only when the original impurities present are high, and when the temperature of casting has been much higher than it should have been, as is frequently the case when very siliceous metal is blown and the charge is not cooled sufficiently by scrapping. In the author's experience, practically all cases of exceptionally bad segregation have been due to some such cause as the above, especially when casting in large ingot moulds has still further facilitated the liquation.

When steel is cast in very small ingot moulds, as in the case of crucible steel, practically no segregation occurs, but the casting of steel in large masses does undoubtedly favour unequal distribution.

Provided that care is taken in the manufacture, and that the temperature of casting is kept well under control, although there will always be some segregation, it should not be a really serious matter in the case of the highest qualities of steel. In the case of rail steels and similar qualities, it is, however, always liable to occur to a greater extent than is desirable.

In Chrome and Tungsten steel there seems considerable liability to segregation, whereas Nickel steels, especially those which contain a large percentage of Nickel, are usually remarkably uniform in their composition.

Talbot † made an exhaustive examination of segregation in acid and

* *Metallurgy of Steel*, p. 206.

† *Iron and Steel Inst. Journ.*, 1905, vol. ii., p. 204.

basic steel ingots, with and without the addition of Aluminium. He concluded that in ingots to which no Aluminium has been added, excessive segregation occurs down the central portion of the ingot, from about 6 inches from the top to half-way down, that Sulphur tends to segregate most, Phosphorus next, then Carbon, and finally Manganese, the segregation of which is so slight as to be almost negligible. The effect of the addition of 4 ozs. of Aluminium per ton was to immediately reduce the amount of segregation, as will be seen from the following figures, taken from analyses of borings from the centre and outside of acid steel ingots.

The borings were taken from top to bottom at distances of 6 inches, and the ingots measured 18 inches × 22 inches × 67 inches.

ANALYSES TAKEN FROM CENTRE AND OUTSIDE OF TWO INGOTS, FROM TOP TO BOTTOM, AT DISTANCES OF 6 INCHES APART.

No.	Without Aluminium.						With Aluminium.					
	Centre.			Outside.			Centre.			Outside.		
	Sulphur.	Phosphorus.	Carbon.	Sulphur.	Phosphorus.	Carbon.	Sulphur.	Phosphorus.	Carbon.	Sulphur.	Phosphorus.	Carbon.
Top.												
1, .	.053	.051	.41	.035	.047	.33	.038	.035	.32	.067	.054	.39
2, .	.049	.052	.39	.031	.034	.32	.042	.040	.35	.066	.057	.39
3, .	.267	.197	.95	.018	.030	.31	.078	.061	.48	.065	.056	.39
4, .	.141	.109	.59	.027	.036	.32	.086	.063	.43	.066	.055	.40
5, .	.097	.083	.47	.034	.040	.35	.081	.049	.34	.068	.067	.41
6, .	.081	.065	.46	.036	.046	.37	.059	.054	.38	.066	.058	.42
7, .	.056	.061	.46	.040	.048	.38	.067	.052	.38	.064	.057	.41
8, .	.056	.053	.38	.041	.046	.38	.057	.049	.36	.058	.052	.41
9, .	.043	.045	.35	.039	.044	.36	.053	.049	.36	.058	.056	.40
10, .	.048	.047	.35	.044	.046	.38	.056	.050	.36	.056	.056	.38
11, .	.047	.045	.34	.048	.048	.41	.057	.047	.37	.060	.053	.38
12, .	.051	.050	.39	.053	.054	.43	.056	.049	.38	.065	.054	.39
Bottom.												

The average analysis of all the drillings taken from the ingot to which no Aluminium had been added was S .059, P .055, C .41; and the average analysis of all the drillings from the ingots to which Aluminium had been added was S .060, P .052, C .39. There can be no doubt, therefore, that constituents whose presence is injurious to the mechanical properties of steel find their way towards the top centre of the ingot. In the case of ingots destined for the manufacture of guns and for other special purposes, the amount of discard cut from the top sometimes reaches 40 per cent., and in the case of steel rails the total discard is usually about 15 per cent., although some engineers specify that not less than 15 per cent. is to be cut off from the top end of the ingot. The importance of this procedure has been widely recognised,* and the effect of segregation must be carefully considered in making large castings and forgings.

* Maitland, *Min. Proc. Inst. C.E.*, vol. lxxxix. (1887), p. 127. See also Eccles, *Journ. Iron and Steel Inst.*, No. 1 (1888), p. 70, and the discussion on Greenwood's paper, on the "Treatment of Steel by Hydraulic Pressure." *Min. Proc. Inst. C.E.*, vol. xxviii., 1889.

Oclusion of Gases by Iron and Steel.

The retention or occlusion of gases by iron was first shown by Graham,* and Parry, on repeating his experiments, obtained most surprising results, especially in regard to the amount of Hydrogen present. More recent investigations by Stead, Muller, and others have shown that although large quantities of Hydrogen, amounting occasionally to five or six times the volume of the steel, are present, that the very large quantities obtained by Parry in some cases were so abnormal as to lead to the opinion that some error must have been made by him, and that the large volumes found could hardly have come from the steel. The presence of this gas, as well as Nitrogen and Carbon Monoxide, in steels at ordinary temperatures is best demonstrated by heating the steel *in vacuo* or by drilling the steel under water or Mercury. A very distinct odour may often be noticed when drilling many kinds of steel, which suggests the presence of these elements in some form which may admit of formation of Hydrocarbons or combination of Hydrogen and Nitrogen.

The difficulty of estimation has led to very various results. Muller † found from 25 to 60 volumes of gas in samples of steel by drilling them under water, while Stead, working on different samples, and drilling under Mercury instead of water, obtained a very small quantity of gas. It has been suggested that the high results obtained by Muller were due to the decomposition of the water, but as no appreciable amount of Oxygen was found in the cooled gases, this could not have been the case, as it is clear that had the Hydrogen been derived from the water, Oxygen would have been liberated at the same time.

A. H. Allen, ‡ many years ago, determined the percentage of Nitrogen in a number of steels, and his results have since been confirmed by the author and Mr. Twynam, § and as much as 0.27 per cent. was found in some cases. The conditions under which Carbon Monoxide and Dioxide are occluded in steel are obscure, but there seems no doubt that Carbon Monoxide, probably derived from the reaction with the Manganese additions, dissolves in steel to some extent.

In an appendix to his paper on the "Determination of the Allotropic Changes of Iron by the Measurement of the Variations in Electric Resistance," Boudouard || gave some analyses of the gases given off on heating different varieties of steel *in vacuo*. Among the gases so examined were Carbonic Oxide, Hydrogen, Nitrogen, and Oxygen, which he found in Carbon and some Chrome steels, whilst from steels containing Tungsten, Manganese, and Nickel he obtained no gas.

G. Belloc ¶ has examined the relation between the temperature and the rate of evolution of gas in steel. With a very mild steel containing 0.12 per cent. Carbon and 0.35 per cent. Manganese the evolution commenced at about 150°, the rate of evolution had a minimum value at about 200°, and a maximum at 400°. Between 500° and 600° a high maximum was obtained, falling to a minimum with the termination of the Ac_2 range. With the commencement of the Ac_3 range the evolution rose, then fell, and again continuously rose with further increase of temperature. Upon heating to 1,200°, a volume of gas equal to from eleven to twelve times that of the

* *Proceed. Royal Society*, 1867.

† *Iron and Steel Inst. Journ.*, 1880, p. 347.

‡ *Ibid.*, 1896, vol. ii., p. 161.

¶ *Comptes Rendus*, vol. cxlv., pp. 1280-1283.

§ *Ibid.*, 1880, p. 181.

|| *Ibid.*, 1903, vol. i., p. 371.

steel was extracted. Up to 400°, the gas consisted almost entirely of CO_2 , which disappears at 550°, above 400° H and CO, and above 550° a quantity of N, not more than 10 per cent. of the gas, was obtained.

The question as to the quantity and effect of Nitrogen in iron and steel has received considerable attention, and H. Braune* has given an exhaustive account of its occurrence and influence on the physical properties.

The following table shows the volume percentage of Nitrogen together with Hydrogen and Carbon Monoxide present in steel made by various processes:—

Nature of Specimen.	Nitrogen.	Hydrogen.	Carbon Monoxide.
Bessemer rail steel,	9.7	90.3	0.0
" spring steel,	18.1	81.9	0.0
" rail steel before introducing spiegel,	10.5	88.8	0.7
" rail steel after addition of spiegel,	23.0	77.0	0.0
Steel before hammering,	5.9	92.0	1.4
" after	23.3	73.4	1.3
Open hearth steel,	30.8	67.0	2.2

Nitrogen may be present in the free state or combined, and it is interesting to note that there are two nitrides of iron known, Fe_4N_2 and Fe_5N_2 , both these compounds, however, are decomposed at temperatures but slightly above their temperatures of formation—namely, 600° to 700°—at higher temperatures decomposition takes place more rapidly.

Many conflicting statements have been made with regard to the physical effect of Nitrogen on steel, some workers have claimed an increase in tensile strength as one of its effects, but most investigators look on Nitrogen as an extremely deleterious element, in view, however, of the discrepancies found in the various determinations of Nitrogen, the conclusions at present put forward must be accepted with every reserve.

T. Baker † has also carried out a research on the nature and volume of the gases given off when steel is heated *in vacuo*, and on the part played by these gases in the production of blowholes.

Table lxxii. gives a summary of his results for a steel without blowholes and a steel of similar composition with blowholes. To prepare these specimens equal quantities of converted bar were melted in two crucibles in the same coke-fired furnace. To one was added a small quantity of Aluminium, and each was cast in a cast-iron mould 6 centimetres square. One of the ingots thus obtained was perfectly sound, whilst the other was full of blowholes. The following is the chemical analysis of the two specimens used:—

	Per cent.	Per cent.
Combined Carbon,	0.81	0.90
Silicon,	0.08	0.88
Manganese,	0.050	0.096
Aluminium, . . . . .	..	0.033
Sulphur,	0.028	0.023
Phosphorus,	0.019	0.019

* *Bulletin de la Société de l'Industrie Minérale*, vol. vii., pp. 489-544.

† *Iron and Steel Inst.*, Carnegie Scholarship Memoirs, vol. i., 1909, p. 219.

TABLE LXXII.

Temperature of Extraction.	Steel without Blowholes.						Weight Taken, 69.31 Grammes.				
	Volume in Cubic Centimetres.						Composition.				
	Total.	CO ₂ .	H ₂ .	CO.	CH ₄ .	N ₂ .	CO ₂ .	H ₂ .	CO.	CH ₄ .	N ₂ .
Degrees C.							Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
519, . . .	6.53	0.07	6.37	0.07	0.02	0.00	1.07	97.54	1.07	0.30	0.00
600, . . .	10.67	0.19	8.44	2.00	0.07	0.00	1.78	79.10	18.74	0.65	0.00
672, . . .	12.87	0.35	8.07	4.40	0.07	0.00	2.71	62.70	34.18	0.54	0.00
688, . . .	22.91	0.75	6.96	15.02	0.12	0.03	3.27	30.38	65.56	0.52	0.13
719, . . .	12.61	0.07	4.74	7.72	0.06	0.01	0.55	37.58	61.22	0.47	0.08
765, . . .	6.71	0.02	3.35	3.26	0.05	0.02	0.29	49.92	48.58	0.74	0.29
802, . . .	4.29	0.00	2.24	1.97	0.08	0.00	0.00	52.21	45.92	1.86	0.00
862, . . .	4.59	0.05	2.24	2.22	0.08	0.00	1.08	48.80	48.36	1.74	0.00
936, . . .	5.04	0.03	2.53	2.42	0.07	0.00	0.59	50.19	48.01	1.38	0.00
979, . . .	5.64	0.01	2.83	2.75	0.04	0.01	0.17	50.17	48.75	0.70	0.17
Total, . . .	91.86	1.54	47.77	41.83	0.66	0.07	..	..	..	..	..
	Steel with Blowholes.						Weight Taken, 63.261 Grammes.				
530, . . .	3.28	0.09	3.04	0.06	0.05	0.04	2.74	92.68	1.82	1.52	1.22
603, . . .	2.96	0.06	2.70	0.08	0.06	0.06	2.02	91.21	2.70	2.02	2.02
681, . . .	4.36	0.06	2.16	2.01	0.15	0.03	1.37	48.39	46.10	3.45	0.69
696, . . .	5.45	0.02	1.49	3.85	0.05	0.04	0.36	27.34	70.64	0.91	0.73
720, . . .	5.04	0.03	1.84	3.11	0.06	0.00	0.59	36.50	61.70	1.19	0.00
762, . . .	3.80	0.02	1.87	1.81	0.09	0.01	0.52	49.21	47.63	2.37	0.26
825, . . .	3.98	0.02	2.01	1.87	0.07	0.01	0.50	50.50	46.98	1.75	0.25
893, . . .	4.24	0.03	2.18	1.93	0.10	0.00	0.71	51.41	45.51	2.35	0.00
944, . . .	4.48	0.02	2.32	2.08	0.05	0.01	0.45	51.78	46.42	1.11	0.22
1,016, . . .	4.50	0.02	3.38	1.05	0.05	0.00	0.44	75.11	23.33	1.11	0.00
Total, . . .	42.09	0.37	22.99	17.85	0.73	0.20	..	..	..	..	..

The extraction of the gas was continued over ten days, the period of heating being eleven hours per day; at the end of each day the gas was collected and analysed. In the case of the unsound pieces, as many as possible of the blowholes were cut open to allow the contained gases to escape, as it was desired to obtain the gases from the solid portion of the steel. On comparing the results, it will be seen that the total volume given off from the *sound* steel was 91.86 cubic centimetres, equal to 10.4 times the volume of the steel employed, whilst from the *unsound* piece the total volume evolved was 42.09 cubic centimetres, equal to 5.2 times the volume of the specimen. It is also seen that the maximum evolution of gas occurs at temperatures which coincide with the Ac_{1-2-3} point for both steels. The commonly accepted hypothesis that the effect of Aluminium in preventing blowholes is due to the fact that it increases the solubility of the gas in the solid metal seems to be confirmed by the above results.

There is practically no conclusive evidence as to the influence of these various gases on the physical properties of steel, apart from the mechanical defects, such as blowholes, produced by their presence; and so far all attempts

to trace any connection between the presence of occluded gases and the strength, ductility, etc., of the steel have failed. It is a well-known fact that pickling often produces a curious brittleness in steel wire, or cold drawn steel tubes, which is completely removed by annealing. This brittleness has been attributed to the absorption of large volumes of nascent Hydrogen, which is again evolved during annealing, and the steel is restored to its ductile condition.

The part played by gases in the production of blowholes in steel is a question of the greatest interest and importance to the steel manufacturer, as when present to an excessive extent they produce unsound ingots which roll into defective finished material. In some cases of what are known as "wild heats," a few seconds after the ingot has been cast, a sudden evolution of gas will cause the whole of the metal to boil over, leaving little more than a shell in the mould. A sudden evolution of gas in this way may be due either to the solvent power of the steel being suddenly reduced owing to alteration in the temperature, or to some chemical action between the steel itself and the various impurities it contains, giving rise to the sudden generation of gas. When steel behaves in this way it will generally be found that, whatever may be the immediate cause of the evolution of the gas, the primary cause is over-oxidation or too high a casting temperature. Thus Bessemer charges very high in Silicon, which blow extremely hot, are liable to become surcharged with Oxygen, which the Ferro-Manganese and Spiegel do not completely remove, and frequently "wild heats" result.

The sudden evolution of the gas in the moulds seems probably to be due to two causes:—(1) By the reduction of the temperature the solvent power of the steel for the gases is lowered, and consequently certain proportions of the gas are liberated; this may apply to the Hydrogen, Nitrogen, and the Carbon Monoxide. (2) An evolution of CO or CO₂ due to chemical action. It has been pointed out, in dealing with thermo-chemistry, that certain chemical reactions take place only within a given range of temperature. It is conceivable that, in the case of a very "hot blow," the critical temperature at which Carbide of Manganese and metallic Manganese are able to reduce Oxide of Iron is exceeded, and consequently the reaction takes place only to a limited extent, until the temperature of the metal is reduced by being cast into the cold mould. This would, to a large extent, explain the sudden evolution of gas which sometimes takes place in ingot moulds, and which it is difficult to explain alone on the hypothesis of gases being liberated from solution.

In good practice the wild heats referred to are comparatively rare, and the blowholes in ingots, although always present, can, by suitable additions of Ferro-Silicon and Aluminium, be so reduced that sound finished material may be relied upon. Even the soundest ingots, if broken through, will be found to contain numbers of blowholes, but as these are generally quite bright and free from oxide, in the majority of cases, they either weld up or are reduced to such a minute size, during the process of rolling or forging, that they are not a source of danger in the finished steel. If this were not so in steel which has been carefully manufactured, the production of sound tubes of thin gauge would be impossible. Sometimes, however, these blowholes are of such a size that they do not close up, and the author is aware of a case of a shaft, 15 inches in diameter, which broke owing to a blowhole 2 inches long, notwithstanding that the shaft had been forged from a very large ingot. In other cases the surface of the holes is coated

with a thin film of oxide, which prevents the perfect welding, and consequently may lead to serious defects in the material when rolled.

Oxygen exists in steel in the form of Oxide; and Law* has recently shown the great influence this has on the physical properties of the steel, especially in the case of tin plates. He described the appearance of Oxide of Iron under the microscope as consisting of minute black specks distributed throughout the mass of the metal. These can only be seen if the specimen has received a perfect polish and requires a magnification of at least 1,000 diameters; besides these Oxide patches, a certain amount of Oxide exists in solution in the iron.

In a number of determinations, the Oxygen was found to vary from 0.021 per cent. in good steels to 0.046 in bad steels; these quantities seem extremely small, but it must be remembered that 0.046 per cent. of Oxygen corresponds to 0.2 per cent. of Ferrous Oxide, which is an appreciable amount of impurity for steels. It is interesting to note that Oxide of iron, when present in steel, has a powerful influence on its liability to corrosion, increasing this to a considerable extent.

Prevention of Blowholes, Pipes and Cracks in Ingots.—The well-known fact that small additions of Silicon and Aluminium largely prevent these blowholes has been explained in two ways—(1) by increasing the solvent power of the steel for the gases and (2) by the removal of the Oxide of Iron and oxidising gases by the oxidation of the Silicon and Aluminium. Probably they act in both ways, as it is clear that Silicon and Aluminium could not remove the Hydrogen or Nitrogen by chemical combination, and hence, so far as these gases are concerned, the first explanation is probably largely correct; but with regard to occluded Oxygen or CO, and Oxide of Iron, it is probable these are largely removed by the reducing action of the Silicon or Aluminium. Further, when metal containing any appreciable amount of Carbon cools down, it is possible that the Carbon may reduce some of the Oxide of Iron present with formation of CO, and if the Oxide of Iron is first removed by Aluminium this reaction cannot take place. Aluminium acts more effectively than Silicon in this way, and this is explained by the greater affinity of Aluminium for Oxygen.

The piping of ingots is not caused by gases in the metal, but is due to shrinkage caused by contraction. The metal at the bottom and sides in contact with the mould is cooled first, and as it contracts the fluid metal in the centre and top tends to act as a feeder, with the result that a cavity is left in the top of the ingot. The position of the cavity will depend upon the regular cooling of the ingot; if cooled equally on all sides; the metal on contraction, acting under gravity, will sink and leave a central hollow near the top. As steel ingots are generally chilled on their top surfaces, the upper end of the pipe may be some little distance from the top of the ingot. If the ingot is laid down in the horizontal position before it has completely set, the cavity, instead of being confined to the top part, will be more or less distributed throughout the entire length, and this is one reason why it is important to heat large ingots in the vertical position, as in soaking pits, rather than in horizontal reheating furnaces. Again, if ingots are cooled unequally from any cause, the pipe, instead of being central, may be more or less on one side of the top of the ingot.

Although the addition of Aluminium and Silicon removes blowholes, it increases the size of the pipe in the ingots, and this is one of the objections

* *Iron and Steel Inst. Journ.*, p. 11, vol. ii., 1912.

to its use, as the larger pipe necessitates a larger portion of the ingot being discarded or scrapped to insure the complete removal of the pipe. Various methods have been introduced for compressing steel ingots while still in the fluid state, with a view of preventing segregation, and decreasing the size of the pipe and the number of blowholes produced during the solidification. Casting under pressure was first attempted by Bessemer in 1856, but was re-introduced and rendered practicable by Whitworth in 1865*; more recently the Harmet† process of compressing steel ingots during solidification in vertical taper moulds, and the Robinson and Rodger‡ method of horizontal compression, have been introduced with considerable success, and both methods are successfully employed in various steel works. All these methods very largely produce the desired results, giving greater homogeneity and freedom from blowholes, and greatly reducing the amount of cropping necessary.

Provided steel ingots could be fed regularly by molten steel during the period of solidification by means of feeding heads, as is done in steel castings, the pipe in the ingots would be largely filled up as the ingots contracted, but though many attempts to carry this out in practice have been made, until recently none have proved successful. It has been suggested to keep the top of the ingot hot by a "thermit" cartridge, which develops intense heat by the oxidation of the Aluminium, and in some works it has been a common practice to cover the top of the ingot with charcoal, but neither of these devices has given very satisfactory results in practice.

The Hadfield Method of Producing Sound Ingots.—Sir Robert Hadfield, in a paper read before the Iron and Steel Institute, entitled "A Method of Producing Sound Ingots," in 1912,§ described a method of casting ingots which he had successfully used in his own works, and which has since been tried by other metallurgists and found to give satisfactory results.

On the top of the ordinary ingot mould is fixed a feeding head about 16 inches deep, which is rammed up with sand, and after the ingot is teemed the sinking head is filled up to within 3 to 4 inches of the top. A layer of ground cupola slag about 1½ inches thick is put on the top of the molten metal, and on the top of this a layer of charcoal, which is maintained at a high temperature by means of a blast of compressed air impinging upon it, as shown in fig. 258a. The slag rapidly fuses and acts as a neutral layer between the metal and the charcoal, largely preventing the latter being absorbed by the steel, and also largely preventing loss of heat by radiation; the heat developed by the combustion of the charcoal maintains the steel in the sinking head in a fluid condition during the cooling of the ingot, and as the steel contracts the pipe which would be formed is filled in by the molten steel from the feeding head, with the result that the pipe is confined almost entirely to the sinking head, and a sound ingot free from piping is obtained.

Ingots of all sizes have been made by this process with satisfactory results, and in a paper read before the American Institution of Mining Engineers in February, 1914, Sir Robert Hadfield gave particulars of a 25-ton ingot made by Mr. G. Charpy, which showed remarkable soundness and freedom from segregation, as shown by analysis taken from centre and other parts of the ingot. Experiments have been made recently in America on rail Steel to determine the relative soundness and quality of the steel as compared with

* Patent No. 3018, 1865.

† *Iron and Steel Inst. Journ.*, 1902, vol. ii., p. 146.

‡ Capron, *Iron and Steel Inst. Journ.*, 1906, vol. i., p. 28.

§ *Iron and Steel Inst. Journ.*, 1912, vol. ii., p. 11.

that produced by the ordinary method of casting, and I am informed that the results are most satisfactory, that the pipe is almost entirely confined to the sinking head, and that the rails rolled from the ingots gave exceptionally good results in respect to freedom from flaws and to mechanical tests.

At Sir Robert Hadfield's own works, where the process is in regular operation, the amount of discard necessary to ensure sound blooms free from pipe or all unsoundness has been reduced by at least one-half.

In carrying out the process it is desirable to use good sound piping steel—i.e., steel which has been deoxidised by use of small additions of Aluminium or Silicon, so that the steel will be as free as possible from blowholes, and to cast the ingots with the larger cross-section at the top.

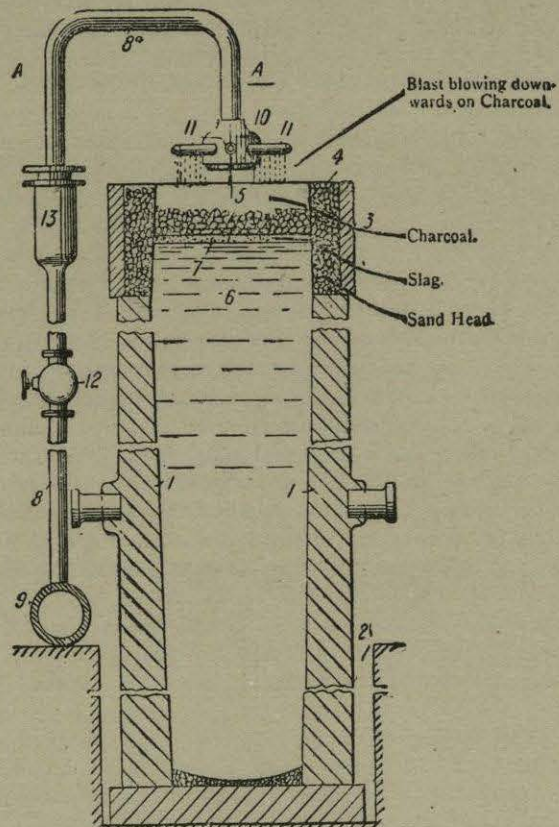


Fig. 258a.—Apparatus employed in producing Sound Ingots, showing the Blast blowing downwards on the Charcoal.

In Fig. 258b are shown photographs of two ingots in section. No. 1 ingot, made by the Hadfield system, is sound, free from blowholes, piping, and segregation. No. 2 ingot, made in the ordinary manner, is unsound, shows blowholes, piping, and segregation.

This method of casting ingots is based on sound principles, and if carried out with care, one would expect it to give extremely good results. It is probably especially applicable to works where steel of high-class quality is made, and where the output is comparatively small, as it would be much easier

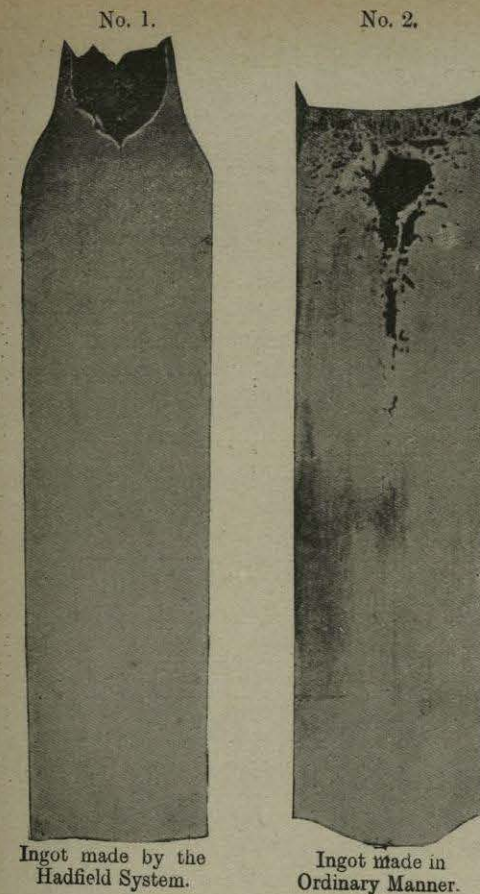


Fig. 258b

to arrange for the heating of the top of each ingot under these conditions than in a works where very large quantities of steel were produced at a very rapid rate as in our large Bessemer or Open Hearth plants, making Rail Steel. In works turning out 5,000 to 6,000 tons of ingots per week it might be somewhat difficult to arrange for the separate heating of each feeding head, but this is largely a matter of design of plant to suit the special

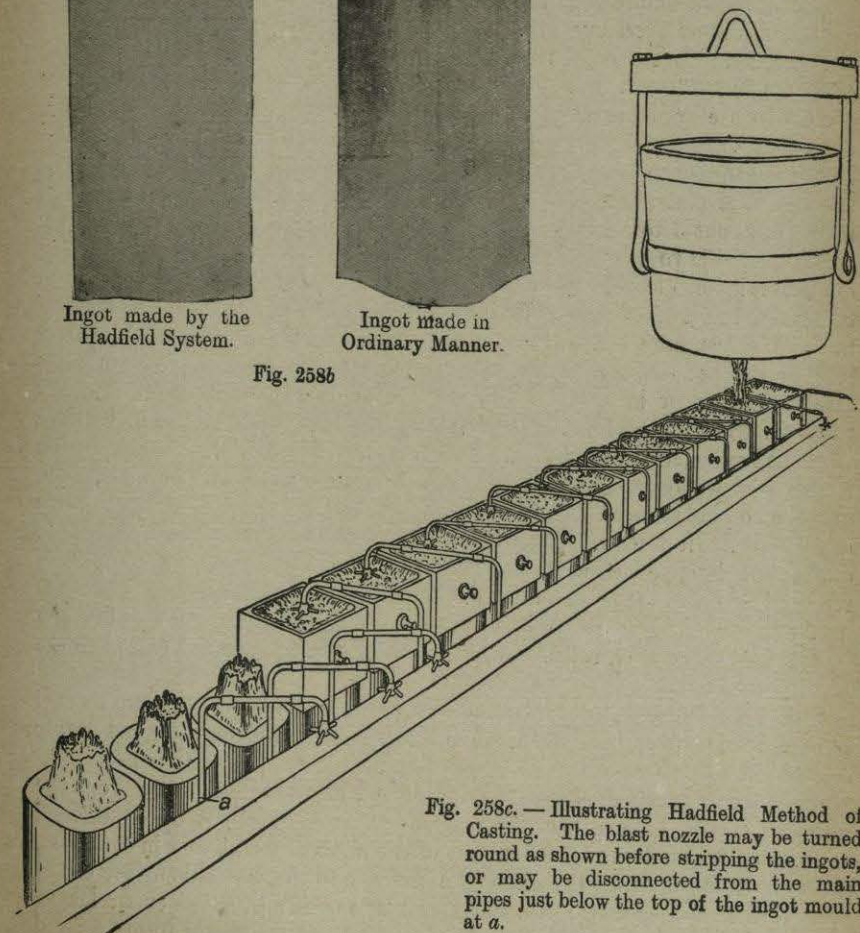


Fig. 258c.—Illustrating Hadfield Method of Casting. The blast nozzle may be turned round as shown before stripping the ingots, or may be disconnected from the main pipes just below the top of the ingot mould at a.

conditions. Fig. 258c shows the arrangement in use at Sir Robert Hadfield's Works, and with some slight modification there seems no reason why this could not be arranged to deal effectively with a large output of ingots from a modern rail plant. It may be found desirable before rolling to cut off the sinking head to avoid any possibility of trouble from split ends in the cogging mill, but only experience will show if this is necessary. The increase in the yield of rails rolled is claimed to be 8 to 10 per cent., and this represents a very large saving in rail costs.

The Talbot Method of Producing Sound Steel.—Mr. Benjamin Talbot has attacked the same problem from a different standpoint. Instead of feeding the ingot by a sinking head, he allows the ingot to cool partially and before it has set, by subjecting it to pressure, he squeezes the liquid portion of the metal into the cavity, or pipe, formed during the contraction due to cooling. So far as the broad principle is concerned, this does not greatly differ from other methods of compressing ingots in the ingot moulds before solidification has taken place, such as the Harmet or Robinson method, but it is in the method of carrying out the operation after removing the ingot mould that the essential difference occurs. Mr. Talbot described his process in a paper read before the Iron and Steel Institute in 1913,* "On the Production of Sound Steel by Lateral Compression of the Ingot whilst its Centre is Liquid," and his process is especially designed to deal with large output of ingots for rail steel and similar purposes. Like Sir Robert Hadfield, he prefers to use good sound piping steel to which Aluminium or some other deoxidising agent has been added to prevent blowholes in the ingot, and he then reduces the cross-sectional area of the top portion of the ingot while the centre is still fluid. The process is more applicable to moderate-sized ingots of about 3 to about 4½ tons rather than to small ingots, as the latter would be liable to set too rapidly. The experiments so far have been conducted on ingots of about 20 inches × 24 inches in cross-section. The addition of Aluminium, apart from removing blowholes, causes the metal to solidify more rapidly than when no deoxidiser is used, and the ingots can, therefore, be stripped earlier. As soon as the ingot has set, about 25 to 30 minutes after removing, it is stripped and transferred to the soaking pit, and left there for from 55 to 65 minutes, by which time the walls of the ingot have thickened sufficiently to withstand the compression, and the central portion is still sufficiently fluid to flow under the pressure; it is then withdrawn, and the top compressed by passing through a cogging mill or other suitable compressor. In the first experiments the whole of the ingot was cogged down, but later experiments showed that the pipe could be completely removed by compressing one-third of the length from the top.

After the ingot has been compressed it is returned to the soaking pit for reheating, and then rolled down into a bloom, cropped, and passed to the rail mill as usual.

Fig. 258d shows longitudinal sections through an ingot allowed to cool as cast, and another ingot from same blow which has been squeezed before the central portion is solid.

It is found that the blooms produced, and also the rails rolled from the squeezed ingots, have a peculiar segregation brought about by squeezing; segregation takes place in the top part of the ingot as usual, and in squeezing the segregated portion is driven by the pressure to the internal surface of the walls of the solid envelope in a fairly regular manner over the entire length of the liquid area, so that the most impure part of the metal forms a band

* *Iron and Steel Inst. Journ.*, 1913, vol. i., p. 30.

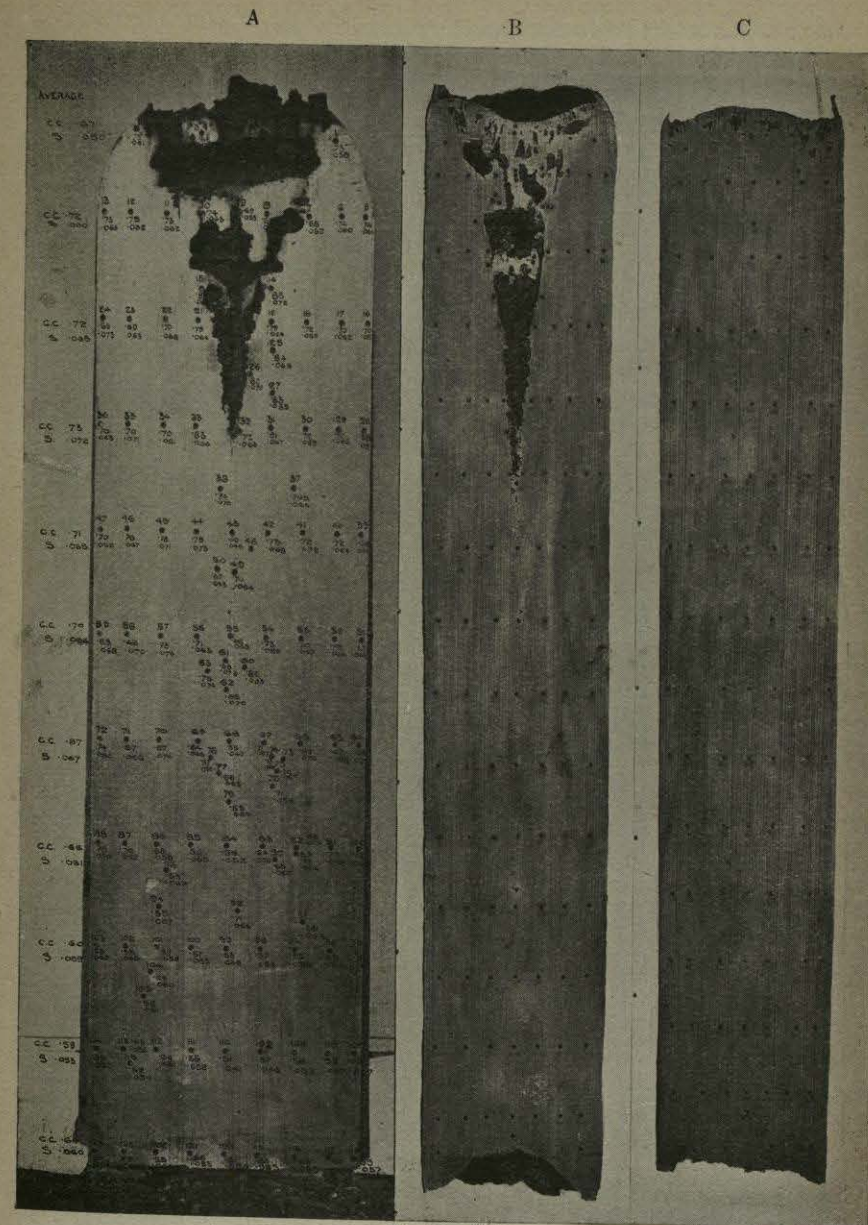


Fig. 258d.

- A.—Ingot cut down longitudinally through the centre, showing cavity.
- B.—Semi-cogged Ingot, cut down longitudinally through the centre, cogged as in ordinary practice, showing the cavity not filled up at this stage (20 × 25-inch ingot cogged down to 18 × 18 inches).
- C.—Semi-cogged Ingot, cut down longitudinally through the centre, cogged whilst centre still fluid, showing cavity to have disappeared at this stage (20 × 25-inch ingot cogged down to 18 × 18 inches).

which is sandwiched between the comparatively purer metal of the outer walls and the comparatively pure metal at the centre. This general formation is retained in the finished rail, the outside and centre being the purest, with a band of segregated metal between them.

Figs. 258*d* and 258*e* illustrates the general structure of the ingot and the finished rails, and an analysis taken from the outer envelope, the dark segregated ring and the central portion gave the following results:—

	Outer Envelope.				Darker Ring.				Central Portion.			
	C.	S.	P.	Mn.	C.	S.	P.	Mn.	C.	S.	P.	Mn.
Average,	0.62	0.058	0.029	0.74	0.69	0.077	0.035	0.78	0.48	0.041	0.022	0.72

Drop and other mechanical tests made on a number of these rails gave excellent results. From a theoretical standpoint, a rail which has the normal material as cast on the outside, in the centre a relatively soft core, and hardest and most impure material sandwiched between the two, might be expected to produce a tougher rail than one in which the impure material is concentrated in the centre as in the ordinary rail.

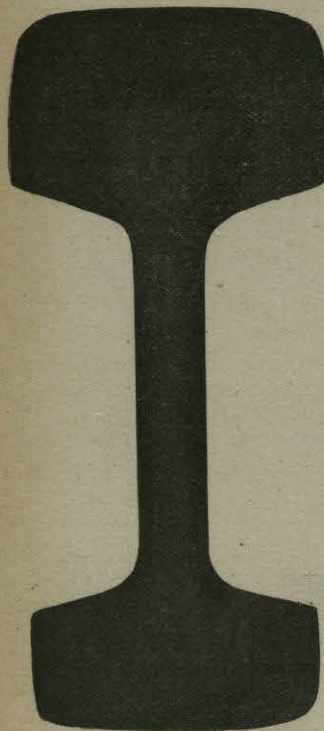


Fig. 258*e*.

this process be a success, the saving in scrap will be a very important matter, as the yield of sound rails will be increased from 8 to 10 per cent. compared with those rolled from the ordinary ingots.

Cracks.—The cracks in ingots which arise from unequal contraction of the ingot in the moulds, may be either longitudinal or transverse. If through careless teeming, or any irregularity in the surface of the mould, the molten steel

The carrying out of the process in practice presents certain difficulties, and whether it will be possible to control the temperature within such limits that there is no danger, on the one hand, of the ingots being too hot, and the liquid segregate squirting out, and on the other, being too cold so that the pipe is not completely closed up, can only be settled by working a plant continuously on a large scale. Mr. Talbot informs me, however, that his experiments with a large number of ingots since he wrote the paper have demonstrated to his satisfaction that the margin of temperature available is ample for all practical purposes to insure regular results. The details of the plant for carrying out the mechanical squeezing have been largely worked out. Mr. Talbot hopes shortly a plant will be in operation to produce rails on a commercial scale. Should

“seizes on” at different levels, this will probably produce transverse cracks, as the ingot itself is contracting and the mould is expanding, and hence the tendency is to tear the surface. If the exterior or shell of the ingot is also cooled much more rapidly than the interior, the rapid contraction of the steel is liable to cause cracks on the surface. As rapid cooling of the outside of an ingot may be the cause of cracks, so if a cold ingot is placed in a hot furnace the rapid expansion of the exterior compared to the interior may cause internal cracks, and in some cases ingots will split quite in two from this cause. It is therefore desirable, whenever possible, to charge the ingots while hot into the furnace, or, in cases where it is necessary to charge them cold, the furnace should be at as low a temperature as possible, and be gradually heated up; this is especially important with high Carbon steel.

CHAPTER XVII.

SPECIAL STEELS OR STEEL ALLOYS.

HITHERTO we have considered steel as consisting almost entirely of iron combined with more or less Carbon, and containing a certain proportion of Manganese. We will now consider shortly the properties of certain special steels, that is of steels which result from mixing with iron other metals with or without Carbon.

Iron alloys readily with most metals, so that the number of steels of this nature which can be produced is necessarily large, moreover it has been found that in many cases a comparatively small difference in the proportion of the added metal makes a very considerable difference in the properties of the resulting special steel. Hence it is easy to see that the field is a very large one, and one that has not yet been fully developed.

In the following pages we shall deal only with the better known of these alloys, some of which are already of the very greatest commercial importance, and with others which are evidently destined to become so as our methods of manufacturing them improve.

The metals which chiefly influence the properties of steel, when admixed with it, may be arranged in a descending scale, as follows:—Manganese, Nickel, Chromium, Titanium, Tungsten, Aluminium, Vanadium, Boron, Uranium, Copper, Tin, Zinc, Bismuth, Lead. Other metals, such as those of the Cerium group, the heavy Platinum metals, etc., doubtless have a very marked effect upon steel when properly introduced into it, but in most cases the field is at present entirely unexplored, or the cost of the added metal renders the resulting alloy too expensive for commercial use.

In this chapter we have taken the alloys formed by steel with other metals in alphabetical order as being most convenient for reference. Copper, tin, zinc, and bismuth are dealt with in the previous chapter, as they are never purposely added, but only occur accidentally as impurities.

Aluminium is usually added to steel, not with the object of forming an alloy, but because of the specific action which the metal has been found to exert on molten cast steel. All steel when in a molten state may be considered to be more or less oxidised, and to contain a greater or less amount of dissolved Iron Oxide, which diminishes both its fluidity and its strength. As this oxidised metal cools, the Oxide, under the action of Carbon, is partially