Analyses of Refractory Materials used for Bessemer Converters and Siemens Furnaces.

Acid or Silicious Materials.

Materials Suitable for Lining Converters.

Ganister.				Silica Bricks.				
	1.	2.	3.		1.	2.	3.	Made from Ganister. 4.
Silica, . .	92·05	94·60	95·20	Silica, . .	96·32	94·80	96·70	94·01
Alumina, .	2·70	1·40	0·59	Alumina, .	1·36	1·40	1·60	2·76
Oxide of iron,	1·85	0·90	0·74	Ferric Oxide,	1·20	1·10	0·65	0·55
Lime, . .	0·60	0·48	0·40	Ferrous Oxide,	nil	nil	nil	nil
Magnesia, .	0·20	0·16	0·16	Lime, . .	1·20	1·90	0·61	2·36
Alkalies, .	0·20	0·14	0·18	Magnesia, .	...	...	...	0·12
Water, .	2·00	2·60	2·70	Titanic Oxide,	...	0·60	...	...
				Alkalies, .	0·21	0·19	0·20	0·18
	99·60	100·28	99·97		100·29	99·99	99·76	99·98

When Silica bricks are used they are frequently jointed with fine ganister, or finely-ground Silica stone, similar in composition to any of the bricks given above.

Materials for Siemens Furnaces.—For the walls, ports, and roofs of Siemens furnaces any of the Silica bricks given above would be suitable as far as the analysis is concerned, all being sufficiently infusible, and they would be set in finely-ground Silica cement containing about 95 per cent. of Silica.

Other questions, however, than those of infusibility, such as contraction and expansion, are very important in determining the selection of a brick for any particular purpose. Thus, although the walls and roof of a Siemens furnace would be built of bricks of similar composition, the texture or fineness of structure of brick selected is often different, coarse-grained bricks being found to give the best results for roofs subject to considerable variation in temperature, and the consequent alternate contraction and expansion. One of the best known bricks used for furnace roofs is the Dinas brick made from the Dinas rock in South Wales. The rock is generally mixed with about 1 per cent. of lime to act as a binding material when made into bricks, which are usually coarse-grained, the rock being only coarsely ground before moulding. The following is a typical analysis:—

Silica, ...	96·80
Alumina, ...	0·92
Ferric Oxide, ...	0·50
Lime, ...	1·20
Alkalies, ...	0·20
	99·62

The Alkalies in all kinds of Silica bricks should be as low as possible, preferably not exceeding 0·5 per cent.

For the regenerators Stourbridge or similar fire-bricks are employed.

Basic Materials.

Dolomite.			Calcined Dolomite.			Magnesite.		Chrome Ore.	
	1.	2.		1.	2.				
Silica, .	1·10	0·90	Silica, .	3·66	2·50	Silica, .	0·92	Silica, .	2·25
Oxide of Iron and Alumina,	1·64	1·30	Oxide of Iron and Alumina,	4·80	3·99	Oxide of Iron and Alumina,	4·40	Ferrous Oxide,	35·82
								Alumina,	3·01
Lime, .	33·20	31·00	Lime, .	55·50	57·32	Lime, .	1·82	Lime, .	4·20
Magnesia,	19·60	20·60	Magnesia,	34·83	34·75	Magnesia,	42·70	Magnesia,	2·60
Carbonic Acid, .	44·30	46·34	Loss on ignition,	1·06	1·00	Carbonic Acid, .	50·01	Chromic Oxide,	51·54
	99·84	100·14		99·85	99·56		99·85		99·42

CHAPTER IX.

THE PRODUCTION OF STEEL CASTINGS.

The production of steel castings is so essentially one of those arts which can be acquired only by long experience, and involves a knowledge of so many little details which are of the greatest importance, that it is impossible to do more than give a very general description and draw attention to some of the more important points which are necessary to success.

In addition to preparing metal of the right composition and casting at the right temperature, two all-important points, the composition of the mould, the method of moulding, disposition of the feeding heads, and means of overcoming excessive local strains in contraction, have all to be anticipated and met to secure a satisfactory result. When it is remembered that many of these points vary with different castings according to their weight, strength required, their complexity or the reverse, it will be seen how impossible it is to lay down any very definite rules, and that each case must be left largely to the judgment of the individual responsible.

Steel Employed.—Castings are made from open hearth furnaces, both acid and basic, but generally the former, and from small tipping converters like the Robert, Walrand, and others, or from crucibles, and excellent results can be obtained with all these processes; the electric furnace is also being used with very good results. For the general purposes of a steel foundry when castings of varying sizes are required, a small open hearth furnace is found to give the best results for all-round work, as greater control over both the composition and casting temperature can be exercised. The essential thing in all steel castings is to obtain solid castings free from blowholes, and for this purpose it is most important to get a "dead melt"—that is to say, to finish with a good, thick, clean, non-oxidising slag. If the finishing slag contains much free Oxide the metal will be over-oxidised, with the result that the casting will be spongy. The slag must at the same time be fluid, so that it does not get entangled with the metal, and carried into the casting, and so cause serious defects, and a little ground Fluorspar added to the metal in the ladle is found to give good results in clearing the metal. The temperature of casting is a most important matter, and will vary to some extent with the size of the casting, hotter metal being necessary for small intricate castings than for large, heavy, thick ones. On the one hand, the metal must not be too hot, or this will cause piping and unsoundness, owing to large and unequal contraction; and, on the other hand, if the temperature be too low, the surfaces of the castings will be defective, and there is a danger of the moulds not filling completely, owing to insufficient fluidity. Experience has shown that, provided the metal be sufficiently fluid, it is better to keep the temperature too low rather than too high, and this is one reason why Aluminium gives such good results in steel castings, as by removing Oxides and so facilitating the flow of metal from the ladle, it enables the steel to be cast at a slightly lower temperature and at the same time insures a good surface on the castings.

It is desirable always to retain a little Silicon and also some Manganese in the bath of metal to prevent over-oxidation, and a little Silico-spiegel and Silicon pig added towards the end of the operation, when the greater part of the impurities have been removed, are beneficial; this addition of Silico-spiegel or Silicon pig tends also to insure sound castings, although it is not so largely used as it was before the introduction of Aluminium, which has, to some extent, replaced it.

The exact way in which Silicon and Manganese act is not thoroughly understood, but there is little doubt considerable portions of the Silicon and Manganese are oxidised to Silica and Oxide of Manganese by some of the oxidising gases present, and, by removing these gases, prevent blowholes. This, however, is only a partial explanation. The action of Aluminium is undoubtedly a reducing one, and the increased fluidity of the metal is in all probability due to the removal of Oxides of Iron. There are strong reasons for believing that Silicon, Manganese, and Aluminium also increase the solvent power of the steel for gases, and thus prevent the dissolved gases being liberated on the steel cooling.

It is important that neither too much Silicon nor Manganese should be added, as the finished casting generally should not contain more than 0·25 per cent. Silicon and about 0·8 per cent. Manganese, and in no case should it exceed 0·55 and 1·2 per cent. respectively.

Aluminium, too, must be added cautiously, especially when making high Carbon castings, as a very small quantity, a few ounces to the ton of metal, is all that is required to produce soundness, and if added in too large quantities, especially to high Carbon steel, it seems to have the curious effect of causing irregular segregation of impurities in the metal, and piping of the ingots. The influence of large quantities of Aluminium on high Carbon steel is a very important question, which has never been completely investigated.

The percentage of Carbon in steel for castings will vary within wide limits from 0·20 to 0·80, or 0·90 per cent., but the great bulk of steel castings contain less than 0·50 per cent. of Carbon, probably about 0·35 per cent.

Phosphorus and Sulphur, although probably not quite so harmful as in structural material, should not exceed 0·06 per cent. each, or, at the outside, 0·08 per cent., and there should be no difficulty in working to these limits, as it simply means selecting high-class pig-iron and scrap. If Sulphur be present to any extent, the castings are very liable to tear during cooling in the moulds, and wasters greatly increase. The proportion of scrap and pig in a casting charge will vary with the grade of steel required, but within reasonable limits any amount of scrap can be used, and in some cases as much as 80 per cent. of the charge, when no ore is added. In most steel foundries the scrap from heads, gits, and wasters is sufficient for the requirements, and is much to be preferred to using outside scrap of more or less unknown composition, although when heavy scrap charges are regularly employed, the foundry scrap will usually have to be supplemented from outside sources. The following table gives a few typical analyses of some steel castings, with the maximum stress, elongation, and reduction of area:—

TABLE LIV.—Steel Castings.

Description of Casting.	Carbon.	Silicon.	Manganese.	Sulphur and Phosphorus.	Maximum Stress per sq. in.		Elongation per cent. on 2 inches.	Bend Test.
					Tons.	Lbs.		Degrees.
Rudder frame, .	0·16	0·49	0·576	Below ·06 per cent. in all cases.	29·6	66,300	37	90 *a.b.*
Shaft bracket, .	·0·21	0·53	0·630		33·8	75,800	23	80 *a.b.*
Eccentric-rod, .	0·20	0·361	...		29·6	66,300	24	120 *a.b.*
Pivot plate, .	0·40	0·326	...		39·2	87,980	24	85
Casting, . . .	0·47	0·501	...		42·0	94,100	14	40
Roller path, .	0·33	0·501	...		41·0	92,000	18	64
,, .	0·22	0·42	0·594		30·3	67,900	29	100 *a.b.*

a.b. signifies that the test pieces bent over to the given angle *without* fracture; in other cases the sample broke or cracked at the angle indicated.

Description of Moulds.—The preparation of the moulds is a most important factor in the manufacture of good castings, and they are divided into two classes, known as "green sand" and "dry sand," the former being generally used for the lighter castings, and the latter for medium and heavier castings.

"Green Sand" Moulds.—This is a generic term for moulds which are not "baked" or dried previously to receiving the molten steel. They are usually made for the lighter class of castings requiring little finish or smooth surface, such as cast steel wheels for colliery waggons, pedestals or "bearings," barrow wheels, &c. The sand of which these moulds are made is ordinary foundry floor sand, which has been strengthened by an addition of a loam sand, and passed through a mixing and grinding mill. Sometimes a small proportion of coal dust is incorporated with this sand, and in "working up" this sand for certain work, small quantities of either beer-dregs or molasses are added. As, however, the sand is "worked" or made up according as the class of work to be moulded varies, there can be no hard and fast rule laid down, and most foundry foremen have their own ideas as to the best mixture for any particular work.

The composition of the added loam sand approximates to the following analyses:—

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
92·50 per cent.	4·56 per cent.	2·14 per cent.	0·60 per cent.	0·32 per cent.

Green sand moulds are made either by hand ramming or machine moulding, and where repetition work for large quantities of castings is required, the latter process, of course, shows considerable economy in cost of production over the former, and invariably better work is produced, as the sand is more evenly and regularly consolidated round the pattern, and the machine admits of a true "draw" of pattern from the sand, thus ensuring a cleaner and "sharper" definition in the mould.

In addition to the mould proper, the "cores" are of great importance; these, of course, are the various shaped pieces or blocks of sand which are laid in the moulds to "cut out" or displace metal, as in the case of the hole in a wheel boss. These are usually made of sand similar to the mould, and must be "vented" to allow of the free escape of gas from the mould to the outside when casting. These cores are invariably dried or baked, even for green sand moulds. After the pattern is drawn from a "green sand" mould, and the mould "cored," it is ready to receive the metal—that is to say, no "paint" or black-lead is put on the surface of this class of mould, as in the case of "dry sand" moulds.

"Dry Sand" Moulds.—This is a term given to moulds usually made of sand with a more or less thick facing of moulders' "facing composition," and used for a heavier and more important class of castings where it is desirable to have a smooth, clean "skin" or surface.

The following analysis represents a steel moulding composition for this class of work:—

Loss on calcination	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O Na_2O
4·84 per cent.	59·81	25·16	5·42	1·14	0·75	3·00 = 100·12

This composition may be made up by grinding and mixing together ganister stone, silica bricks, fire-bricks, old plumbago crucibles, and small quantities of coke.

In preparing the mould a layer of sand is spread out on the bottom of the "box," and carefully smoothed over. This is then covered with a layer of moulders' "composition," varying according to the size of the casting, to, say, ½-inch or more in depth. On this the pattern is now placed, and a layer of "composition" spread over it, sand sifted over this, and the whole rammed to the pattern. The pattern is then withdrawn from the mould, both of them being always made in two or more pieces, and the face of the latter is coated with black lead wash, Silica paint, or with a mixture of both. The moulds are then "stoved"—*i.e.*, placed in drying stoves—where they are heated *very gradually*, otherwise they are liable to split or crack owing to the too rapid escape of steam or to the too sudden expansion of the mass of sand. The time necessary for drying any particular mould must depend upon its size, thickness, and shape; but it is of the greatest importance to make quite sure that the mould is absolutely dry before the metal is run into it, otherwise serious defects will probably appear in the casting, and there is also a danger of accidents from the metal being blown out of the mould by a sudden generation of steam.

On removing the dried mould from the stove, it is usual to coat the surface with coal tar or black lead, and either to put it back in the stove for a short time or to rely upon the initial heat of the hot mould to dry this coating.

The "venting" of moulds and cores, the disposition and sizes of the feeding heads, the position of the runners, the anticipating and dealing with contraction, local strains, &c., &c., are all points of the greatest importance, to which in steel foundry practice attention has to be given to a considerably greater extent than in iron foundry work.

Internal Stresses in Castings.—One of the greatest difficulties the steel founder has to overcome is that of fracture of the casting, due to "shrinkage" or internal stresses caused by contraction of the metal in passing from the liquid to the solid state during cooling down.

Steel founders have endeavoured to overcome this trouble in a variety of ways, such as liberating the sand of the mould from some parts of the casting as soon after pouring as possible, removing the core so as to allow of free contraction, comparatively quick cooling of the heavy parts in relation to the lighter parts, and also by a system of "tying" thick and thin parts of the casting by either brackets of metal or "dogs"—*i.e.*, bent iron bars cast in locally to form ties. The amount of shrinkage varies with the composition and heat of the metal; the softer and hotter the metal the greater is the shrinkage; but as smoother castings are obtained from hot metal, it is better in many cases, where this is of special importance, to cast hot and allow for shrinkage.

Shrinkage varies from 1·5 to 1·8 per cent. or even 2 per cent., according to the composition and heat of the metal—say, equal to about $\frac{3}{16}$ inch to the foot.

Annealing the Castings.—Castings of very hard steel have a tendency to crack (or "fly") when cooling; but this tendency can to a great extent be counteracted by efficient annealing, which removes, or, to a great extent, reduces, the initial stresses set up in the metal while passing from the liquid to the solid state in the mould, and thus toughens the casting. The regular and gradual heating of castings during annealing, and the temperature of annealing, are very important questions which are now receiving considerable attention at the hands of steel founders; and in many works, especially where very large and costly castings are made, recording pyrometers are attached to the furnaces, so that any irregularity in the working of the furnace, whether from negligence on the part of the workmen or other causes, is at once discovered. The temperature usually employed is about 900° C. for low Carbon castings, and somewhat less (about 800° to 850°) for castings containing above ·50 per cent. Carbon; but the annealing temperature which produces the greatest strength, combined with ductility, in castings containing different percentages of Carbon, has not been fully threshed out, and is being investigated by several metallurgists. In a paper "On the Properties of Steel Castings," read before the Iron and Steel Inst., Prof. Arnold * gives the results of heating his experimental bars of pure Carbon steels for 70 hours at a temperature of 950° C., with slow cooling for another 100 hours, this temperature being selected because Prof. Arnold has found it is frequently reached in works' practice. The results are given in Table lv., and are of interest as forming the basis for a complete series of researches, but are not comparable with results obtained from commercial steels.

The time of heating and of cooling will largely vary with the weight and the shape of the casting, and one great difficulty in annealing castings is to anneal the different parts equally, as sometimes it takes many hours to heat the body of the casting through, and all this time the lighter parts are exposed to a long soaking.

The general effect of annealing castings is similar, only more marked, to that produced on annealing rolled or forged steel—viz., a removal of internal stresses, accompanied with increase in elongation and contraction of area, and decrease in maximum stress; in other words, the casting is toughened. Unannealed castings are nearly always more or less brittle when subjected to shock, and annealing very largely removes this brittleness.

The few examples in Table lvi. show the effect of annealing and also of oil tempering on castings or forgings containing different percentages of Carbon, and may be taken as fairly representative.

* *Iron and Steel Inst. Journ.*, 1901, vol. i.

TABLE LV.—PROF. ARNOLD'S RESULTS ON ANNEALING SMALL IRON AND CARBON CASTINGS MOULDED IN DRY COMPOSITION

Mark.	Process.	Analysis. CC.	Si.	Mn.	S.	P.	Al.	Specific Gravity.	Tensile. Elastic Limit. Tons per sq. in.	Maximum Stress. Tons per sq. in.	Elongation per cent. on 2 ins.	Reduced Area. Per cent.	Bending ⅝-inch Radius.	Compression per cent. at 100 Tons per sq. in.	Remarks.
FeB	Crucible	0·07	·023	·05	·02	·01	·018	7·9162	10·69	19·79	30·0	38·7	180° U	62·3	As cast
		0·07						7·9249	9·10	19·18	46·0	65·1	180° U	63·0	Annealed
473	,,	0·06	·06	·07	·02	·02	not estimated	7·9954	11·53	17·48	18·5	28·5	180° U	62·7	As cast
		0·06						7·9247	8·83	16·91	18·5	30·9	180° U	64·4	Annealed
521	,,	0·18	·01	·09	·027	·01	·023	7·8868	11·85	19·92	19·5	29·1	180° U	61·8	As cast
		0·16						8·0141	9·35	19·51	31·0	47·0	180° U	61·9	Annealed
458	,,	0·37	·05	·08	·03	·02	·02	7·9164	14·71	21·77	5·0	5·9	40°	55·5	As cast
		0·37						7·9761	10·28	20·84	12·5	19·8	180° U	58·9	Annealed
518	,,	0·37	·04	·10	·023	·017	·025	7·9842	15·95	23·22	6·0	6·3	32°	56·2	As cast
		0·37						8·0925	9·00	21·97	20·0	22·4	180° U	57·7	Annealed
CC	,,	0·42	·04	·06	0·2	·01	not estimated	7·8510	17·22	23·41	6·5	8·4	90°	45·7	As cast
		0·40						7·8653	10·08	24·03	24·5	29·0	180° U	50·0	Annealed
541	,,	0·44	·076	·03	0·3	·016	·032	7·9560	13·33	24·62	8·4	12·3	43°	57·3	As cast
		0·35						7·9782	12·21	23·50	14·0	16·0	180° U	62·3	Annealed
CC2	,,	0·48	·09	·10	0·2	·02	·022	7·8937	18·38	18·38	3·0	3·2	12°	52·3	As cast
		0·50						7·9607	15·21	26·75	20·5	15·7	86°	56·3	Annealed
YB	,,	0·50	·075	·07	·022	not estimated.	not estimated	8·0449	17·53	19·28	2·5	1·7	12°	50·8	As cast
		0·54						8·0054	10·52	25·28	16·0	18·4	180° U	55·5	Annealed

Mark.	Process.	Analysis. CC.	Si.	Mn.	S.	P.	Al.	Specific Gravity.	Tensile. Elastic Limit. Tons per sq. in.	Maximum Stress. Tons per sq. in.	Elongation per cent. on 2 ins.	Reduced Area. Per cent.	Bending ⅝-inch Radius.	Compression per cent. at 100 Tons per sq. in.	Remarks.
517	Crucible	0·56	·08	·08	·031	·019	·037	7·8981	15·74	22·98	3·0	3·5	23°	48·6	As cast
		0·50						7·9644	12·32	25·32	10·0	10·0	135°	53·3	Annealed
556	,,	0·60	·073	·07	·031	·018	·028	7·9276	16·92	18·80	1·5	1·8	13°	51·0	As cast
		0·60						7·9533	9·80	16·49	2·0	2·4	33°	55·0	Annealed
601	,,	0·70	·11	·10	·045	not estimated	·050	7·8954	18·52	20·12	1·5	1·8	5°	47·2	As cast
		0·72						7·8612	13·92	30·32	6·0	5·3	30°	51·3	Annealed
459	,,	0·86	·06	·05	·02	·02	·018	7·9468	26·48	26·48	1·5	2·1	0°	broke at 54 tons per sq. in.	As cast
		0·80						7·9580	15·48	23·76	2·5	4·2	18°	45·4	Annealed
524	,,	0·97	·058	·03	·025	·018	·030	7·9054	22·25	32·42	2·0	1·8	8°	sheared at 90·4 tons per sq. in.	As cast
		0·83						7·9600	18·54	29·03	4·0	1·7	50°	50·7	Annealed
460	,,	1·29	·098	·28	·02	·02	·042	7·8788	22·30	22·30	0·0	0·0	0°	33·1	As cast
		1·10						7·8536	16·55	29·93	2·5	3·5	20°	40·7	Annealed
522	,,	1·95	·034	·02	·015	·016	·031	7·8454	13·18	13·18	0·0	0·0	0°	broke at 99·5 tons per sq. in.	As cast
		1·10						7·8771	12·86	12·86	0·0	0·0	3°	58·5	Annealed
573	,,	1·76	·058	·07	·020	·022	·020	7·7424	20·32	20·32	0 0	0·0	0°	17·3	As cast
		1·38						7·7661	11·69	14·11	0·0	0·0	5°	52·7 sheared	Annealed

TABLE LVI.—EFFECT OF ANNEALING.

Carbon.	Unannealed.			Annealed.		
	Tensile Strength or Maximum Stress per sq. inch.		Elongation per cent. on 2 inches.	Tensile Strength or Maximum Stress.		Elongation per cent. on 2 inches.
Per cent.	Tons.	Lbs.		Tons.	Lbs.	
·23	30·68	68,780	22·40	30·00	67,220	31·40
·37	38·18	85,300	8·20	36·70	82,220	21·80
·53	40·23	90,100	2·35	47·50*	160,480	9·80

Carbon.	Silicon.	Manganese.	Unannealed.				Annealed.			
			Tensile Strength per sq. in.		Elongation per cent. on 2 inches.	Reduction of Area.	Tensile Strength per sq. in.		Elongation per cent. on 2 ins.	Reduction of Area.
Per cent.	Per cent.	Per cent.	Tons.	Lbs.		Per cent.	Tons.	Lbs.		Per cent.
0·30	0·22	0·63	33·6	75,220	16	26·8	31·0	69,500	24	43 8
0·50	0·40	0·66	44·4	99,500	2	4·13	44·0	99,520	12	16·8

The following figures show the effects of "annealing" and "hardening" and "tempering":—

C.	Si.	Mn.	S.	P.	Fe.	Annealed.					Hardened and Tempered.				
						Tensile Strength per sq. in.		Elastic Limit per sq. in.		Elongation per cent. on 2 ins.	Tensile Strength per sq. in.		Elastic Limit per sq. in.		Elongation per cent. on 2 ins.
Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Tons.	Lbs.	Tons.	Lbs.		Tons.	Lbs.	Tons.	Lbs.	
·35	·023	·252	·019	·038	99·35	34·4	77,080	17·6	39,500	27	48·9	109,560	29·06	65,090	16·5
·43	·028	·216	·023	trace	99·30	34·9	78,180	19·26	43,100	25·5	49·6	111,100	31·1	69,700	17·0

The first five results were obtained on castings and the last two on samples taken from a forged gun-jacket, hardened by quenching in oil at about 820° and re-heated to 650°. Annealing, especially in the case of high Carbon castings, does not seem to appreciably lower the maximum strength, although it decreases the elastic limit, and it largely increases both the elongation and the reduction of area.

* This is an abnormal result, although a slight increase in the maximum stress on annealing is not very uncommon.

CHAPTER X.

THE PRODUCTION OF SHEAR AND CRUCIBLE STEEL.

The Cementation Process.—Notwithstanding the immense development, in recent years, of the Bessemer and Siemens processes, special varieties of high Carbon steel continue to be made from what are known as "cement bars," by the converting or cementation process, which has so long been practised in the Sheffield district, and according as these carburised bars are piled and welded together, or fused in crucibles and cast into moulds, they are respectively known as shear or crucible cast steel.

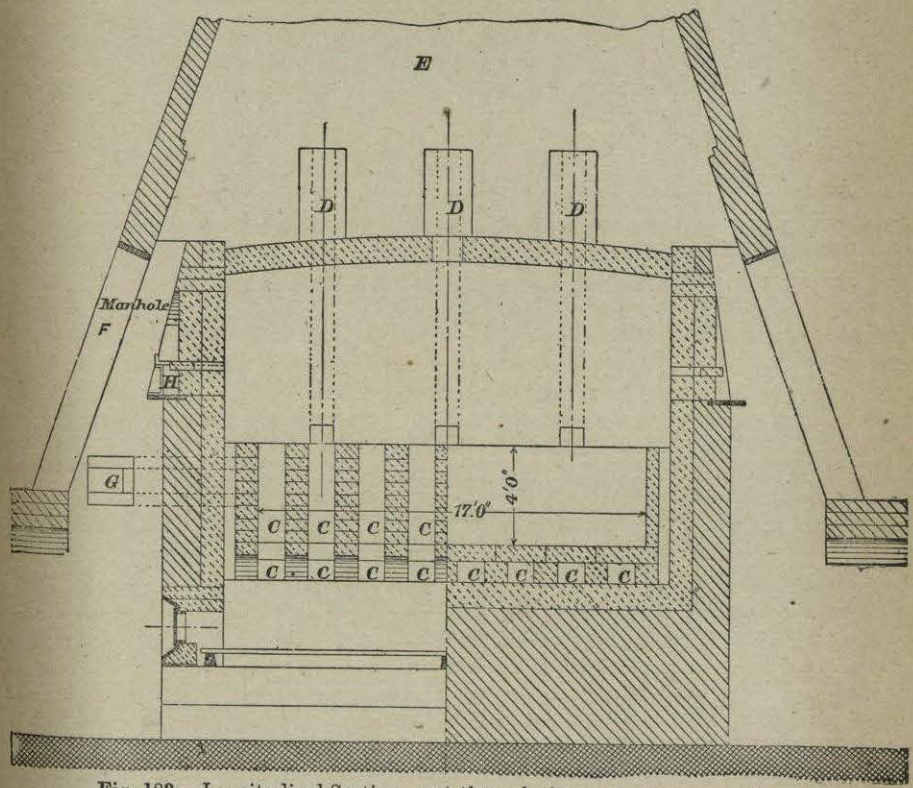

Fig. 183.—Longitudinal Section, part through the converting pot, and part through the flue.

The cementation process depends upon the well-known fact that iron, when heated with exclusion of air in contact with Carbon, absorbs that element in varying proportions which depend upon the time the operation lasts, and the temperature at which it is conducted.

Figs. 183 and 184 give transverse and longitudinal sections of an ordinary cementation furnace, in which wrought-iron bars are heated, in contact with Carbon, for varying periods according to the degree of carburisation required.