

as long as the boxes and furnished at the two ends with two feeding doors. The grate is lower than the bottom of the boxes. The products of the combustion circulate uniformly around the two boxes and in the space left free between them, through a series of channels formed of refractory bricks, the dimensions and the arrangement of which (as is seen with special clearness in Fig. 74) are so planned as to obtain good uniform heating of the two boxes. Complete uniformity of temperature of the boxes is obtained better, during the heating, by partially closing the mouth of the flues corresponding to the parts of the boxes in which by chance an excessive rise in temperature is observed.

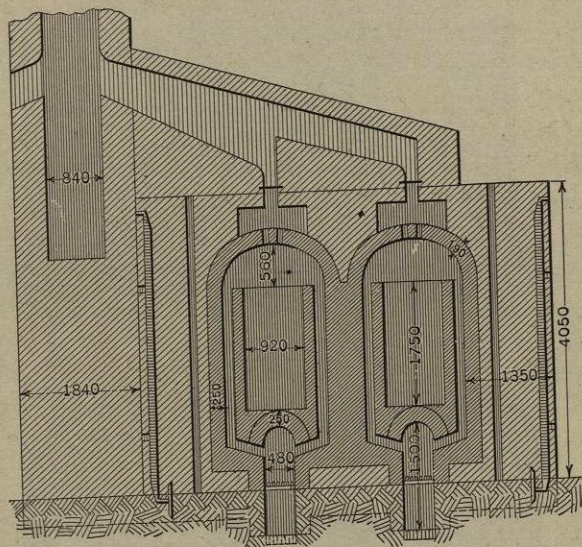


FIG. 75.

The hot gases issue from the chamber through a series of small openings made on two sides of the arch and at the base of it, and from here, through short passages, they pass into a conical chamber of bricks, which covers the whole furnace and is open only at the top. In the two minor walls of the refractory chamber are made two openings which permit of the entrance of workmen into it during the charging of the furnace. Before beginning the heating, these openings are walled up with refractory bricks.

The usual dimensions of the boxes are from 2.50 m. to 4.50 m. in length by 80 cm. to 1 m. in height and in width. Boxes of these dimensions can hold from 6 to 12 tons of iron, together with the necessary quantity of cement.

The outside walls of the boxes are always pierced with one or more holes through which are passed iron bars ("spies") which remain partially immersed in the cement. The examination of these bars, removed from the boxes from time to time, furnishes useful indications as to the course of the cementation. Figs. 75 and 76 reproduce two sections of a furnace constructed

on principles identical with the preceding but differing from it in several structural elements, especially in the construction of the refractory chamber containing the two boxes. The characteristics of the construction of this furnace follow clearly from the two figures herewith reproduced.¹

Other similar types of cementation furnaces are also constructed, in which, however, every box is heated by a separate hearth, so that the various boxes can be kept at different temperatures.

The great advantages of gas fuel, both as to economy in fuel and greater ease and perfection with which the heating can be regulated and made uniform, explains the present tendency to substitute for the old cementation furnaces, heated directly with solid fuel, other furnaces heated by producer gas.

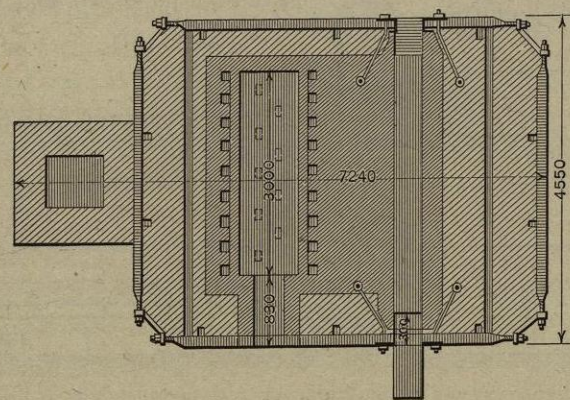


FIG. 76.

As an example, we may show here a modern type of cementation furnace heated by producer gas, and used both for total cementation and for superficial cementation (case hardening).

It is represented, in longitudinal and transverse section, in the two figures, 77 and 78.² The gas, produced by the producer *A*, reaches the furnace through the channel *C* and is burned in *D* by a jet of air under pressure; the flame, after having passed over the cover and the sides of the cementation chamber until it reaches the front end of the furnace, returns to its rear end through the two channels *F*, made, under the box, in the mass of refractory bricks constituting the box itself, and passes then from the conduits *F* to the channel *G* and from this to the chimney. The refractory system constituting the box and the two channels for the return of the flames *F* is placed on a car, so that, the operation being finished and the door of the furnace opened, all that is necessary is to draw out the car and quickly substitute for it another similar one, into whose refractory box the bars of iron and the cement have

¹ The four figures (73-76) are taken from Ledebur's *Handbuch der Eisenhüttenkunde*.

² This furnace is described by Engineer C. W. Bildt; *Jernkontorets Annaler*, 1901, abstracted by *Stahl und Eisen*, 1902, I, pp. 438-440.

already been loaded. In this way the process takes place much more rapidly than with the other furnaces with fixed boxes, for the operations of charging and emptying the boxes are carried on outside of the furnace, and it is not necessary to wait for the latter to cool. It is easy to understand how this arrangement has the advantages of greater rapidity of the operations, of greater productive capacity, and of great economy in fuel.

I do not think that experimental data on the working of this furnace have been published, and I have never

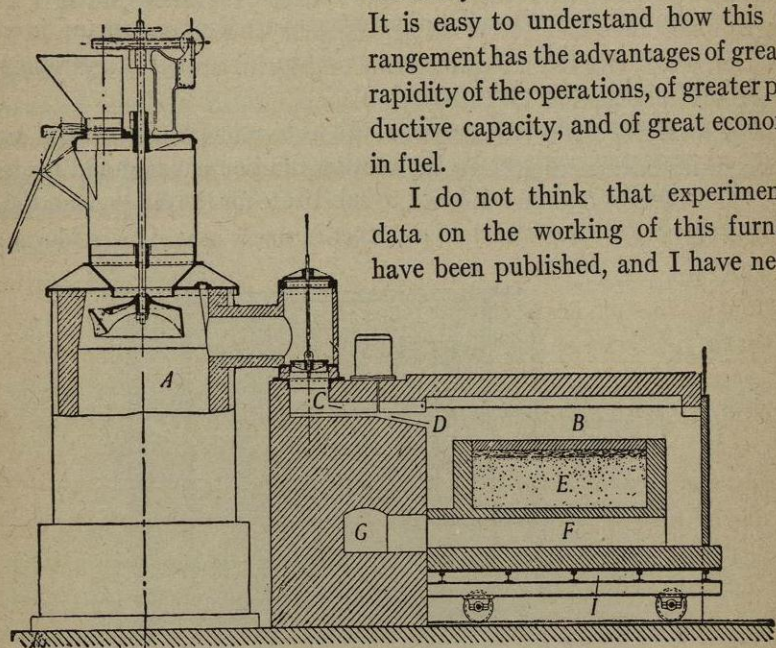


FIG. 77.

had opportunity to study it in operation. However, judging it *a priori* on the basis of furnaces similarly constructed, I would consider that its fundamental defect consists in the way in which the channels *F* are connected with the channel *G*. In fact, in the furnaces of this kind which I have had

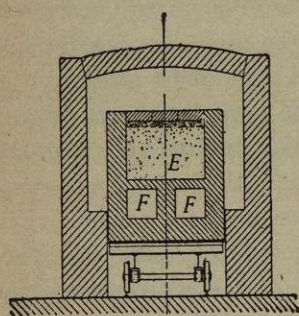


FIG. 78.

occasion to use, I have always observed that after prolonged operation, which wears out the movable ends of the canals and makes them irregular, it was not possible to obtain a sufficiently tight connection between the fixed channel *G* and that on the car *F*, so that sometimes a considerable part of the gases, instead of following the longer course *DBFG*, followed the direct way *DG* to the chimney. The immediate consequence of this is a large difference in temperature between the two ends of the box, which is more highly heated toward *D* than toward the door of the furnace.

Whatever may be the type of the furnace used, the charging of the cementation boxes, when solid cements are employed, is done as follows: On the bottom of the refractory box is placed a layer of fine refractory earth, a couple

of centimeters thick, intended to fill the cracks which may eventually be formed during the heating of the furnace, so as to prevent oxidizing gases from penetrating into the cementation boxes and impeding the carburization of the iron. Above the refractory earth is placed a layer of carbon in coarse powder and fragments (or of any other solid cement), 5 to 8 cm. thick, on which is placed a first layer of the iron objects to be cemented. The shape most commonly adopted for these is that of flat bars 10 to 20 mm. thick by 50 to 100 mm. wide; the bars must be about 10–20 cm. shorter than the cementation boxes in order that between their ends and the walls of the boxes a sufficient quantity of carbon may stay, even when the bars have expanded as a result of the high temperature of the furnace. The bars of iron must be placed flat and carefully surrounded by the cement; they must not touch each other, nor touch the walls of the boxes.

On the first layer of iron bars is placed a second layer of carbon, 1 to 3 cm. thick; on this a new series of bars; then more carbon, and so on in this way until the last layer of carbon reaches to within 10 cm. of the upper edge of the box; then the whole mass contained in the box is covered with a layer of already-used cement, and on this is placed a last layer of a refractory powder capable of preventing the access of furnace gases into the interior of the box. Usually, this is the powder formed when pieces of steel are polished or steel utensils are sharpened on siliceous grindstones. This powder is composed of grains of silica mixed with particles of steel, and possesses the property of agglomerating or sintering at the temperature of the cementation furnaces, forming a mass impermeable to gases. This property is probably due to the fact that the particles of steel are oxidized by the action of the furnace gases and form with the silica a partially fusible slag which cements to each other the particles forming the rest of the mass. In many cases simple refractory clay is used for the same purpose. The covering is usually completed with a layer of refractory bricks.

When wood charcoal is used as cement, in the form of powder mixed with small grains the size of peas, the charge is usually made in the proportion of 35 to 45 liters of carbon to 100 kg. of iron. Taking into account the space occupied by the "bottom" of refractory earth and the "cover" of earth and bricks, the space occupied by the iron bars rarely exceeds 35% of the total available space in the boxes.

The trial bars, called *spies*, are placed in the boxes by introducing them through the holes which we saw were made for this express purpose in the outer walls of the boxes and (corresponding with the former) in the outside walls of the working chamber of the furnace. They are put in place during charging when the charge has reached the level of these holes.

The charging of the boxes being finished, the furnace is closed. This, in furnaces with fixed boxes, consists in walling up the working doors and luting with refractory clay the interstices around the trial bars. Then the fires

are lit and the temperature of the furnace raised to bright red or yellow heat. This temperature, which corresponds to 1050–1150° C., is usually reached in from forty to sixty hours, according to the dimensions and type of furnace used. Then the temperature is kept constant for seven to eleven days, according to the degree of carburization which it is desired to obtain, taking care to heat the boxes everywhere to as uniform a temperature as possible. This is quite easy when using gaseous fuel, and also in furnaces with solid fuel by regulating, by refractory bricks, the size of the upper openings of the channels through which the gases of the furnace circulate within the boxes.

In general, the judging of the temperature of the furnace is left entirely to the experience of the furnace foreman, who estimates it on the basis of the color of the boxes. It is well known that such an estimate is very uncertain, especially since it depends on the variable conditions of illumination of the plant in which the furnace is placed.

In order to avoid harmful "heat waves," *i.e.*, strong local rises in temperature which may cause the melting and therefore the loss of a part of the iron already carburized, it is sometimes customary to place on the cover of the boxes, or near to them at other points of the furnace, "Seeger cones" of different numbers, which serve quite well to regulate the temperature.

Although so accurate and easy to use, I have never seen optical or electrical pyrometers employed in works for the cementation of fusion-steel. The employment of registering pyrometers would be especially easy and advantageous.

As already said, the temperature at which cementation is effected strongly influences the results of the operation. We know that the depth to which the carbon penetrates into the iron in a given time is greater the higher the temperature, so that, at least from the point of view of rapidity of operation and output of the plant, it is profitable to keep the temperature of the furnaces as high as possible, within permissible limits. Too high temperature causes excessive concentration of the carbon and risk of melting the external layers of the partially cemented bars.

Usually, it is considered good practice that the temperature for effecting total cementation must be close to the melting of copper (1085° C.).

If, instead of the usual cement containing a mixture of used and new charcoal, only new charcoal is used, or a more active cement, such as the mixture of carbon and barium carbonate, it is necessary to work at a lower temperature, to avoid too intense carburization; in this case it is necessary to prolong the heating somewhat, in order to extend the carburization to the desired depth.

The length of the heating varies according to the cement used and the product which it is desired to obtain. When the usual mixture of new and used wood charcoal is used, the length of the heating at full heat is about

seven days if the steels are to be used directly after simple forging of the separate bars, eight days if the steels are destined for subsequent piling in fagots and forging, nine to eleven days, according to the degree of carburization it is desired to reach, if for steels intended to be melted in crucibles.

But even when always using the same materials, inevitable variations in the temperature of the furnace render necessary direct control of the carburization, so as to be able to interrupt the operation at the proper moment. For this control, the trial bars or *spies* are often placed in the cementation boxes in such a way that they can be removed during the operation. When it is judged that the cementation is reaching its end, one of the trial bars is removed, quickly closing up the hole with refractory luting material. The examination of the surface of fracture of the bar, broken either after slow cooling or after tempering, preceded or not by forging, permits of judging with some approximation the time during which the heating must be continued to obtain the desired degree of carburization.¹ To the examination of the fracture, which necessarily gives imperfect results, is sometimes added a quantitative determination of the carbon in a sample of the metal taken from the external layers of the bar. Results just as rapid, but far more accurate and complete, can be obtained by subjecting to microscopic examination a plane transverse section of the bar allowed to cool slowly. This microscopic examination can be carried out in less than ten minutes, not requiring a complete polishing of the section, and it furnishes directly data of the highest accuracy, both as to the depth the carburization has attained, the maximum concentration reached by the carbon in the bars, and the distribution of the carbon in the mass or its concentration in the various layers of the iron. This last datum is of great importance when the cemented bars are to be used directly, without undergoing such subsequent treatment (*e.g.*, fusion) as is capable of making the concentration of the carbon homogeneous. This knowledge is, in any case, most useful in judging whether it is necessary to change the temperature of the furnace toward the end of the operation.

The reason this test is not usually made is the quite widely diffused, but erroneous, belief that a micrographic examination requires a costly equipment. Such a supposition is entirely unfounded, for the apparatus and the adjuncts necessary to effect a micrographic control of the cementation certainly do not cost more than two or three hundred lire (forty or sixty dollars), and the work of control can be carried out by the workman supervising the furnace, to whom the necessary instructions can be given.

The further duration of the heating is regulated on the basis of the results of the examination of the trial bars, taking into account the fact that after the fires are extinguished a considerable time is necessary before the tempera-

¹ It is not possible to describe the structures of the *spies* characteristic of the various stages of the cementation. Only long experience can give skill in recognizing, by examination of their surfaces of fracture, the stage reached by the cementation.

ture of the boxes is lower than that at which cementation can take place. This datum, which depends upon the quickness with which the furnace cools and therefore varies from one furnace to another, can be judged only on the basis of previous operations carried out in furnaces of the same type and of the same dimensions.

Usually, it requires from four to seven days for the furnace to cool so far as to permit the entrance of workmen to empty the boxes.

The quantity of fuel burned during the cementation varies between very wide limits, with variations in the nature of the fuel itself and with variations in the type of the furnace. In ordinary grate furnaces for the direct use of solid fuels, for every ton of cement steel there is usually burned from 750 to 900 kg. of cannel coal, or from 1600 to 3000 kg. of lignite or peat, or from 3000 to 3500 kg. of wood. In furnaces with wood gas producers, the consumption of this fuel is reduced to about 2000 kg. per ton of cement steel.

The length of an operation, including the time necessary for charging, emptying, repairs, etc., varies, in general, between twenty and thirty days. It is seldom that more than fifteen cementations can be made in one year in one furnace.

The cemented bars are broken and subdivided into groups, in the way I shall describe later, on the basis of the appearance of their surface of fracture. This method of classification is of slight accuracy.

English manufacturers, in general, "classify" the cemented bars into seven groups, or "numbers," according to their approximate carbon content as judged from examination of the fractured bars. The first group includes the least carburized bars, in which the fracture shows very clearly the "nucleus" of unchanged iron remaining; the second includes steels in which the mean carbon content is about 0.5%; the bars of No. 3 contain on an average from 0.8 to 1% of carbon; those of No. 4 from 1 to 1.3%; those of No. 5 from 1.3 to 1.5%; those of No. 6 from 1.5 to 1.8%; and those of No. 7 (designated by the name of "doubly converted bars") about 2%.¹ The bars which on account of heat waves in the furnace have undergone incipient surface fusion are classified separately and designated by the name of "glazed bars." Finally, the bars which have undergone superficial refining or oxidation, produced by the entrance of air through cracks formed in the boxes or through badly luted joints in the cover, are also classified in a separate group and are called "aired bars." These superficially decarburized bars are easily recognized, as their surfaces of fracture are characterized by a peripheral zone possessing the characteristic crystalline and lustrous structure of oxidized or "burnt" steel.

It is very difficult to describe, even approximately, the characteristic appearance of the surface of fracture of the cemented bars, and even more

¹ These products of such high-carbon content are really obtained, usually, by means of two successive cementations.

difficult to give indications for recognizing from this appearance the approximate carbon content. Only long practice and continuous and attentive observation of the bars of the different classes permits the most able workmen to make a good classification on the basis of this primitive method of observation.

An inexperienced eye can recognize with certainty only *very highly* carburized bars, from 1.5 to 2% of carbon, by examining the surfaces of fracture of the *non-hardened* bars. These are characterized in such high carbon steels by the presence of many brilliant plane surfaces of cleavage, due to the fact that the fracture is effected chiefly along the brittle laminae of cementite (Fe_3C) which penetrate in great quantity the mass of steels highly carburized by cementation.

Moreover, not all manufacturers make so minute a classification of their products. Many of them begin by leaving aside the bars not sufficiently cemented, those that remain almost as malleable as the original iron, and those which have undergone a more or less deep refining; both the former and the latter are subjected again to another cementation. Then they also leave aside the bars which have undergone incipient fusion, and limit themselves to subdividing the others into three groups, according to their degree of carburization.

As regards the appearance of the external surface and of the surfaces of fracture of all cemented bars in general, two essential characteristics are present, easily recognized even by those who have not such an experienced eye as is necessary to make the classification to which I have just referred. The first consists in the fact that the surface of cemented *wrought iron* bars no longer has the metallic appearance, the continuity and the uniformity which the iron bars had before the cementation; but it is coarsely opaque, of brown color, and covered with "blisters" or "beads" varying in size from a pea to a walnut, scattered over the whole surface of the bars.

It is considered an indication of good quality in the product when these "beads," "bubbles" or "blisters" are small, uniform, uniformly distributed over the surface of the bars, and especially when they do not collect in marked abundance along definite lines.

To these characteristic blisters are due the names by which cement steel bar is designated in various languages. Thus, in English it is called *blister steel*; in French, *acier poule*; and in German, *Blasenstahl*.¹

¹ In the report containing propositions for "a uniform nomenclature of iron and steel" presented in September, 1909, by M. H. Howe and A. Sauveur before the Congress of International Associations for Testing Materials, *acier poule* or *blister steel* is defined simply as "steel obtained by carburizing wrought iron (*ferro saldato*) by heating it in contact with substances rich in carbon," and it is added that "it can likewise be obtained by carburizing a steel of low carbon content."

The authors of the report consider that any steel obtained by cementation should be called *blister steel* or *acier poule*, whether it shows the characteristic blisters or not.

As to the origin of the blisters or "beads" characteristic of steel obtained by cementing *wrought iron*, many different hypotheses have been advanced; but the knowledge of their causes would have no importance for practice, because the phenomenon does not occur in those cases in which it would produce the most harmful effects, that is, in the partial cementation of objects of cast steel which are not to undergo any other treatments after the cementation other than hardening and fitting.

In general, the tendency to-day is to regard as correct the hypothesis proposed by Percy as early as 1864. According to this, the "blisters" are formed by the local evolution of carbon monoxide, formed by the action of the carbon which diffuses into the iron on the slag, rich in oxides, contained in the form of specks in the iron. As is seen, this hypothesis in its simplest form, presupposes that the carbon diffuses into the iron as such and not in the form of carbon monoxide. Therefore, assuming that we now know that the penetration of the carbon occurs chiefly by the agency of the diffusion of carbon monoxide into the iron, Percy's hypothesis needs some modification.

It does not seem that there can be any doubt that the formation of "blisters" is due to the presence of slag. In fact, as early as 1878 Percy showed that if iron is subjected to cementation after having been fused, so as to eliminate the slag, the "blisters" are no longer produced, although the cementation proceeds, in all other respects, in exactly the same way as when ordinary iron is used. Moreover, as previously stated, the surface cementation of finished objects of fused soft steel, destined not to undergo further forging or fusion, is possible just because of the fact that with this material, totally (or almost entirely) free from slag, the "blisters" are not formed.

The second easily recognizable characteristic of the structure of cemented bars of soft iron or steel consists in the fact that their structure varies markedly from the outside to the center. For example, a bar quenched at about 800° in cold water and then broken, shows the "grain" of the surface of fracture fine and compact (though of variable fineness and compactness) at the outer edge and for a portion corresponding to over 0.4-0.5% carbon; within this zone and to the center of the bar, the metal gradually resumes its original characteristic crystalline structure.

This variation in the "grain" of the metal from the periphery to the center of the cemented and hardened bar gives approximate indications as to the "depth" reached by the cementation; but, as we shall see better later, the results which are thus obtained correspond only within quite wide limits with the precise data furnished by the microscopic examination of the suitably etched and polished sections, or by the chemical analysis of the material obtained from successive layers of the bars. This must be taken into account when it is desired to estimate, from the examination of the trial bars or "spies," the point to which the cementation has progressed.

The only precise information which can be obtained from these observa-

tions is the absence or the presence of the "nucleus" with crystalline structure; if absent, the bar is certainly "core" cemented, while if present the carburization has not reached to the center of the bar and is limited to a more or less deep enveloping zone.

The real distribution of the carbon in the deep cemented zones, as found by chemical analysis of successive layers, has been already discussed in the first part of this book, referring there to various practical data. To complete what was there given, we will report here some data relative to other industrial cementation operations; a comparison of these with those before given will show still more clearly the strong variations which small differences in the conditions of working, such as temperature, composition of the cement, etc., produce in the results of the operation.

The data contained in the following table are due to Bildt, and refer to a bar of Lancashire iron cemented with a mixture of sixty parts wood charcoal and forty bone ash, for thirty hours at 1100°-1200° C.

Depth (mm.)	Carbon, percent.	Depth (mm.)	Carbon, percent.	Depth (mm.)	Carbon, percent.
Surface	1.0	3.0	0.35	6.2	0.09
0.8	1.0	3.8	0.12	7.0	0.045
1.5	0.8	4.6	0.11	7.7	0.040
2.3	0.5	5.4	0.10	...	.....

The table which follows reports the results of analyses of successive layers made by Arnold¹ on cemented bars classified, according to the standards of English manufacturers to which I have already referred, by the numbers 2, 3 and 4. The last column contains the data relative to a bar of No. 4 which had undergone incipient refining, an *aired bar*.

Layer	Depth (inches)	Percent of carbon			
		Bar No. 2	Bar No. 3	Bar No. 4	Bar No. 4, refined
1 (surface)	0.02	0.98	.....	.....	.....
2	0.04	0.95	1.40	1.50	.....
3	0.06	0.76	.....	.....	0.30
4	0.08	0.63	1.26	1.45	1.20
5	0.10	0.50	.....	.....	1.45
6 (middle)	0.12	0.39	1.15	1.27	1.45
7	0.14	0.37	.....	.....	1.45
8	0.16	0.31	1.10	1.29	1.40
9	0.18	0.18	.....	.....	1.38
10	0.20	0.15	0.98	1.29	1.38
11	0.22	0.10	.....	.....	1.35
12 (center)	0.24	0.10	0.88	1.15	1.16
Mean carbon content.....	.....	0.45	1.13	1.33	1.04

¹ *Journal of the Iron and Steel Institute*, 1898, Vol. II, p. 185.

In the bars of Nos. 5 and 6 (from 1.4 to 1.8% of carbon), the concentration of the carbon does not vary appreciably from the periphery to the center.

As to the composition as a whole of the cemented steels, it is, aside from carbon, quite similar to that of the iron used, as the cementation can not give rise, to a marked degree, to any other effect (neglecting the probable penetration into the steel of small quantities of nitrogen, coming from the air occluded in the cement or from the cement itself) than that of raising the carbon content of the iron used as raw material.¹

The table which follows gives the results of analyses of some cement steels reported by Wedding:

No.	Quality and source of cemented steel	Amorphous C, (a) per cent.	Graphitic C, per cent.	Si, percent.	P, percent.	S, percent.	Mn, percent.	N, percent.
1	From Elberfeld, soft.	0.416	0.80	.....	.....	.....	.....	.....
2	English, forged and hammered cold.	(Total C—1.87)		0.10	.....	.....	.....	.....
3	English, forged and hammered cold,	0.627	0.105	0.03	.....	0.005	0.120	.....
4	English, forged.....	1.20	0.30	.....	.....	.....	.....	0.016
5	English, forged.....	1.24	0.30	.....	.....	.....	.....	.....
6	English, hardened..	1.48	0.02	.....	.....	.....	.....	0.016

(a) Includes, evidently, the hardening and carbide carbon.

And I add, in the table which follows, the data reported by Helson (*La Sidérurgie*) relative to the composition of three French cemented steels:

	I	II	III
Carbon	1.750	1.200	0.960
Silicon	0.063	0.055	0.060
Sulphur	0.004	0.004	0.007
Phosphorus	0.007	0.013	0.013
Manganese	0.030	0.050	0.070

From these data and from those already given relative to the composition of the types of iron most frequently used for the manufacture of cement steel, it is evident that in reality cementation does not appreciably modify the composition of the metal except by increasing the carbon; this explains the great purity of the steels which can be obtained with this process. This purity is perhaps the only reason for the better quality of the steels obtained

¹The weight of the cemented steel is, in general, about 0.5–0.75% greater than that of the iron used to make it.

by carburizing pure wrought irons *without melting them*, and therefore the cause of the survival of this industry.¹

As regards the state in which the carbon is present in the cemented steels, I reproduce the following data, reported in part by Ledebur² and in part by Thallner.³

No.	Quality and source of cemented steel	Hardening carbon, percent.	Carbide carbon, percent.	Annealing carbon, percent.	Total carbon, percent.
1	Steel from the Bismarckhütte with very coarse grain (Thallner).	0.66	0.82	.....	1.48
2	Steel from the Bismarckhütte with coarse grain (Thallner).	0.60	0.82	.....	1.42
3	Steel from the Bismarckhütte with fine grain (Thallner).	0.745	0.765	.....	1.51
4	Id. (Thallner).....	0.68	0.63	.....	1.31
5	Steel from the Bismarckhütte with very fine grain (Thallner).	0.54	0.47	.....	1.01
6	Steel from Remscheid (Ledebur).....	0.19	0.97	0.04	1.20
7	Swedish steel (Ledebur).....	0.42	1.07	.....	1.49

It is seen from these data that cemented steels of these types do not contain annealing carbon (except traces in No. 6), a fact which accords well with their very low silicon content. The relation between the quantity of hardening carbon and that of carbide carbon depends naturally on the thermal treatment to which the steel has been subjected. Thus, from the numbers of the preceding table, it follows that while Steel No. 6 has been allowed to cool slowly in the boxes below the temperature of hardening (first critical point), the others have been removed from the boxes while they were still red hot and then suddenly cooled.

As I have already said, it is seldom that the cemented bars are used directly,⁴ on the one hand because of the "blisters" and on the other on account of the non-homogeneous distribution of the carbon which ordinarily results from the process of cementation. The maximum differences in carburization are observed between the ends and the central parts of the bars,

¹The investigations of Boussingault, already referred to (see p. 23), would show that cementation, carried out under the conditions usual in industry, reduces the sulphur content in the iron treated; a reduction which may sometimes amount to as much as 80% of the initial sulphur content. According to the same investigations, the phosphorus and silicon contents, on the contrary, undergo a very slight increase, which may be attributed to the action of the ashes of the wood charcoal used as cement. It is a question, however, in these last two cases, of phenomena which, owing to their very small extent, have no practical importance.

² *Handbuch der Eisenhüttenkunde*, 4th edition, p. 1085.

³ *Stahl und Eisen*, 1899, II, p. 914.

⁴ Cemented bars, subjected to only a simple forging or rolling, constituted for a long time the material most commonly used for the manufacture of springs. English manufacturers, in fact, called the material thus obtained *spring steel*.

the former being always more carburized than the latter, and between the periphery and the "nucleus." Moreover, there are often present, even in bars contained in the same box, strong "accidental" variations in carburization, due to non-uniform heating of the various parts of any box, imperfect contact of the iron with the cement at given points, etc.

In these cases, where a product of perfect homogeneity is not required, it is sufficient to pile pieces of sorted bars into packets or bundles, which are then subjected, one or more times, to heating in hearths or in reverberatory furnaces and to forging or rolling. We can not enlarge here on the details of these operations; they are applied, as is well known, to steels of most varied sources, and form an important operation of the general metallurgy of iron. We will merely mention the necessity of always heating the packets and the bars in a neutral atmosphere and under the protection of a slag or of clay, so as to avoid decarburizing the steel. Notwithstanding these precautions, however, the finished product is always less carburized than the bars used, and only long practice permits of selecting the bars of the "grade" adapted for obtaining a definite product. The steels obtained by the re-heating and forging of packets of cemented bars are still to-day largely used for the manufacture of cutlery of all kinds.

When, on the contrary, it is desired to obtain a product perfectly homogeneous and free from slag, recourse is had to fusion of the cemented bars; this is almost always done in crucibles,¹ but has quite recently begun to be done in electric furnaces.

Of this process, also, it is not in place here to give detailed information, for while the technology of this process has nothing to do with that of cementation proper, its applications, extending to the fusion and manufacture of steels obtained by processes different from cementation, would lead to a chapter of the metallurgy of iron which has nothing to do with cementation. On the other hand, excellent and exhaustive treatises on the processes of crucible fusion of steel are to be found in many treatises on iron.

We will, therefore, report in the following table only the chemical analyses of three steels obtained by fusing cement steels in crucibles, simply to show within what limits this last treatment influences the composition of those cement steels whose greatest value is their purity.

The numbers reported below are taken from the paper of Thallner already quoted from:

	No. 1	No. 2	No. 3
Carbon.....	1.31 percent	1.44 percent	0.96 percent
Manganese.....	0.14 "	0.14 "	0.13 "
Silicon.....	0.05 "	0.10 "	0.09 "
Phosphorus.....	0.010 "	0.015 "	0.012 "
Sulphur.....	0.003 "	.....	.....
Copper.....	0.011 "	.....	.....

¹As we have already seen (see p. ix), the invention of the process of crucible fusion of steel is due to Benjamin Huntsman (1735-1740).

As is seen, the product obtained by crucible fusion preserves almost unchanged the purity of the cement steel fused.

It is well to point out that it is difficult to avoid oxidation during the fusion and the formation of blowholes when casting steels of the composition of those indicated above. So that, usually, in charging the cement steel to be fused there are added de-oxidizing alloys such as ferro-manganese and ferro-silicon, adapted to furnishing a de-oxidized steel without blowholes. This is the reason why crucible-fused cement steel usually contains more manganese and silicon than is normally found in the raw materials. It is true that sometimes the reason for the higher content of manganese and silicon is quite different, and is simply the fact that the steel sold as "crucible-fused cement steel" is not such, but comes from the Bessemer converter or the open-hearth furnace!

In the crucible fusion of cement steel, the desired "grade" or carbon content is obtained either by charging into the crucible pieces of accurately classified cement bars, all chosen of the necessary homogeneous grade, or by charging bars of a higher grade and then suitably lowering the carbon content by the direct addition of softer bars or of iron itself.

As regards the cost of cement steel, it is easy to understand that it is not possible to furnish in general precise data because of variations in the local and temporary prices of the raw materials and in labor, fuel, refractory materials, etc. From the data of many works in which the production of cemented steel is carried out on a large scale we may consider as the minimum 45 lire (\$9) and the maximum 110 lire (\$22) per ton of steel produced. We mean to indicate by this the sum to be added to the price of the raw material (soft iron or steel in bars) to obtain the "industrial" cost (including, that is, labor, depreciation, repairs, general expenses, etc.) of the bars of cemented steel in the state in which they are removed from the cementation boxes.

As an example may be cited the cost of cementation in the basin of the Loire, which still produces considerable quantities of cement steel for fusion. This cost oscillates on the average between 55 and 80 francs (\$11 to \$16) per ton of product.

The use of gaseous cements, proposed by MacIntosh in 1825 (see p. xiii), has found wide application in the processes of partial cementation but has not given good results in total cementation, so that to-day it may be considered as abandoned in the industry of the cementation of wrought iron bars to steel.

On the contrary, the processes of cementation based on the use of mixed cements, solid and gaseous, have found wide application, even for making cement-steel for fusion, especially owing to the fact that they give very rapid cementation and guarantee absolute purity of the product. But the introduction of these processes has not yet extended as far in the production of fusion steels as in the production of partially cemented steels.