proved by a simple comparison of the experimental data reported by various authors. Some data of this kind, determined by Guillet, have been already reported in the form of diagrams in the first part of this volume (see p. 49). We copy here the exact values (depths of the cemented zones in tenths of a millimeter) obtained in these experiments of Guillet, in order to facilitate comparison with other data.

(*a*) Cementation of an ordinary soft cabron steel *eight hours* at different temperatures and with different cements.

Temperature	Composition of the cement			
	60 parts of carbon + 40 parts of barium carbonate	2 parts of potassium ferrocyanide + 1 part of potassium bichromate	Potassium ferrocyanide	Wood charcoal in fine powder
700° C.	0.0	0.0	0.0	0.0
800°	5.0	8.5	5.0	5.0
900°	22.5	17.5	20.0	12.5
1000°	35.0	32.5	32.5	25.0
1100°	45.0	45.0	50.0	35.0

(*b*) Cementation of same at 1000° C. during various times and with different cements:

Time (hours)	Composition of the cement					
	60 parts of carbon + 40 parts of barium carbonate	Ferrocyanide + bichromate	Unwashed animal charcoal	Wood charcoal		Carbon + potassium carbonate
				In fine powder	In coarse powder	
1	8	8.5	9.0	7.5	7.0	15
2	10	9.5	15.0	13.5	11.0	20
4	12	12.5	22.5	16.0	15.0	24
6	20	19.0	27.0	18.5	17.5	28
8	30	32.5	32.5	25.0	23.5	35

More recently[1] Guillet himself determined more precisely the data relative to the cement formed of forty parts of barium carbonate and sixty of carbon, reporting the following numbers:

Penetration desired (mm.)	Length of cementation at a temperature of 850° C.	Length of cementation at a temperature of 1000° C.
0.5	2 hours 30 minutes	0 hours 30 minutes
0.8	4	1
1.0	6	2
1.2	7	3
1.5	8	4
2.0	..	6
2.5	..	8

[1] *Le Génie Civil*, 2d sem., 1911, p. 228.

Guillet points out that to avoid serious mistakes it must be remembered that in the table reported above the length of the cementation is calculated from the moment at which the box is *externally* at the temperature 850° and 1000° C. Moreover, the numbers reported above hold for boxes of sheet iron in the form of cylinders 120 mm. in diameter, in which the objects to be cemented are placed coaxially and in such a way that around them there is a layer of cement 5 cm. thick.

As is seen, the numbers reported hold only for very special conditions and it is not possible to furnish for solid cements data of entirely general character.

The results obtained with a given solid cement vary within wide limits even with small variations in the conditions of working: for example, with variations in the form and dimensions of the boxes and objects to be cemented; in the arrangement of these objects and cement in the boxes; in the construction and working of the furnace used, etc.

Thus, to cite only a few of the numerous examples which might be given, in a table reported by Lake[1] for cementation carried out with the usual cement of carbon and barium carbonate for eight hours at 900° C., we find a penetration of 2.75 mm. instead of the 2.25 mm. given by Guillet or the 2.20 mm. obtained by Shaw Scott,[2] or the 1.2 mm. obtained by Grayson[3] by cementing for seven hours at 950°–1000° C. Thus also, by cementing with charred leather at 900° C., while Grayson obtains in six hours a cemented zone of 0.035 inch, Lake, under the same conditions, obtains in four hours a zone of 0.062 inch; that is, almost double the value in two-thirds the time.

The differences between the results obtained by various experimenters in the cementation of special steels are still greater. Thus, for example, Guillet, cementing a steel with 2 percent. of chromium under conditions where an ordinary carbon steel would have given a cemented zone 0.9 mm. thick, obtains a cemented zone 1.1 mm. thick, while Giesen,[4] to obtain about the same penetration (1.2 mm.) with the same 2% chromium steel, protracts the cementation for ten hours at 1100°, using the mixture of carbon and barium carbonate. Under the same conditions Guillet obtained, with a carbon steel, a penetration of 4.5 mm. in only *eight hours!*

Many of the wide divergences between data of this kind reported by the various authors must without doubt be attributed to the different (and often absolutely inexact) ways of estimating the depth of the cemented zones. It is not possible, however, to carry out a cementation with a solid cement, charging the boxes cold as usual, in such a way as to be sure to obtain

[1] E. F. Lake, *Composition and Heat Treatment of Steel* (New York, 1911, p. 235).
[2] *The Journal of the Iron and Steel Institute*, 1907, III, p. 126.
[3] *The Journal of the Iron and Steel Institute*, 1910, I, p. 298.
[4] Walter Giesen, *Die Spezialstähle in Theorie und Praxis*, p. 20.

cemented zones of a definite depth and with a given maximum carbon content.

The course of the cementation *under the average conditions which present themselves in practice*, when ordinary soft steels are cemented with the cement formed of 60 parts of wood charcoal and 40 of barium carbonate, is seen in a diagram (Fig. 114) due to Guillet,[1] which gives (in tenths of a mm.) the penetration of the carbon in successive hours when the cementation is conducted at a constant temperature of 850° C. and the steel subjected to the cementation contains 0.12% of carbon. The following diagram (see Fig. 115), along similar lines, is due to Shaw Scott.[2]

Scott's three curves indicate in mm. the penetration of the carbon in

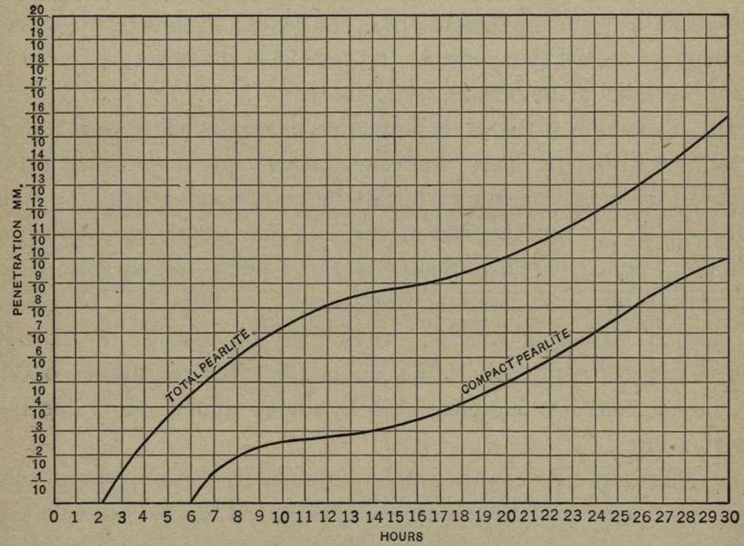

FIG. 114.—Curves of the penetration of the carbon at a temperature of 850° C. into a steel with 0.12 percent of carbon.

successive hours, when cementing ordinary soft steel at 900° C. with three different solid cements:

1. Carbon cement (40 parts of barium carbonate and 60 of wood charcoal (highest curve);
2. Carbonized leather (intermediate curve);
3. Wood charcoal (lowest curve).

As regards the action of solid cements proper on various special steels, we have up to the present few experimental data. Even these few data are not very reliable, or, at least, can not serve as guides in the various cases arising in practice, since they hold only when the cementation is conducted in a manner absolutely identical with that used for their determination.

[1] See *Mém. de la Soc. des Ing. Civ. de France*, 1904, p. 192.

[2] *The Journal of the Iron and Steel Institute*, 1907, III, p. 127.

In the cementation of special steels with solid cements great variations in the characteristics of the cemented zones, due to very small differences in the conditions under which the cementation has been effected, are much more prominent than with plain carbon steels. In fact, outside of the few data given by Guillet, and already reported in the first part of this volume, the data given by other experimenters must be considered as lacking in any practical value whatsoever.

As an example of this, take the results of Giesen, in which any practitioner can point out large and evident errors. From his Table 7 (p. 19), it would follow that a steel with 0.5% of manganese, cemented for one hour at 850° C. with leather carbon, is carburized to a depth of 0.982 mm., while in the same steel, cemented for ten hours at 1100° C., the carburization reaches

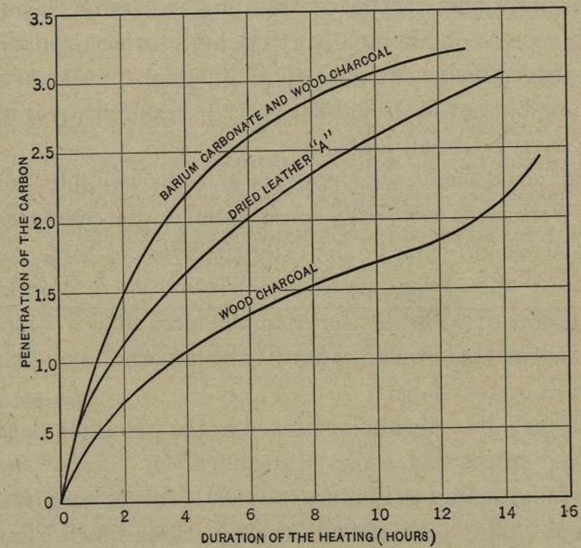

FIG. 115.

only 1.213 mm.! It must be noted, however, that Giesen determined the penetration of the carbon by weighing the specimens of steel before and after the cementation!

We have seen, and we shall see again, that the causes of error noted above do not show themselves at all, or to a much smaller extent, in cementation carried out with gaseous cements or with mixed cements.

Besides the velocity of the penetration of the carbon, another datum, of still greater practical importance, must be taken into account in judging of the quality of a cement and in the choice of the cement best adapted to a definite purpose; the maximum concentration and the distribution of the carbon in the cemented zones, as shown by the curves which we have called "cementation curves."

In cementation with gaseous cements or with certain mixed cements it is possible to choose the conditions of the cementation in such a way as to obtain with certainty cemented zones in which the concentration of the carbon does not exceed a definite value and varies from one layer to another of this zone in the most "gradual" manner, thus avoiding, or at least enormously reducing in extent, the phenomena of brittleness and exfoliation of the cemented and hardened zones. In cementation with solid cements it is not possible to even approximate results of this precision.

Under the action of "quick" solid cements the concentration of the carbon rises rapidly in the external layers of the cemented zone. This becomes more marked the greater the velocity with which the temperature of cementation is reached and the higher this temperature. Cements of this group are advantageously used when it is necessary to cement to a small depth but to attain high carbon contents in the external layers of the cemented zones, so as to obtain rapidly a very hard surface, and where it is not necessary to reduce their brittleness to a minimum. Such are articles subjected to friction but not to strong shocks, as, for example, gear wheels always engaged and carrying small loads.

The "mild" or "slow" solid cements give, by suitably prolonging the cementation, very deep cemented zones without the concentration of the carbon rising too high, even in the external layers of these zones. These cements are used with advantage whenever it is desired to obtain cemented zones of medium or great depth (for example, more than 1–2 mm. and up to 25–30 mm.) and such as present, after hardening, minimum brittleness and minimum tendency to exfoliate.

Of the various solid cements mentioned in the preceding pages, there are generally placed in the first group of "sudden" or "quick" cements those which I have indicated by the letters (*A*), (*B*), (*E*), (*G*) and (*H*), and in the second group of "mild" or "gradual" cements those which I have indicated by the letters (*C*), (*D*) and (*F*). But, from the point of view of the concentration and distribution of the carbon in the cemented zones, this simple subdivision has no absolute value whatever, for the same cement may act, according to the way in which the cementation is conducted, as a "sudden" cement or as a "gradual" cement.

Thus, for example, Caron's cement (60 parts carbon and 40 barium carbonate) is a "gradual" cement when used at temperatures below 900° C. and to cement objects of large dimensions (which heat up slowly); in this case it can furnish cemented zones more than 2 mm. thick, in which the concentration of the carbon does not exceed 0.9% even in the surface layers. The same cement, on the contrary, becomes "sudden" when it is used at temperatures higher than 1100° C. to cement objects of small dimensions; under these conditions it can furnish cemented zones in which the maximum concentration of the carbon may exceed 1.5%.

Analogous examples might be cited for the greater number of the solid cements.

It is clear, therefore, why the few present known "cementation curves" relative to the solid cements practically employed are very far from being as accurate as those for the gaseous cements and the mixed cements. Nevertheless, we will cite here some of the empirical data relative to some solid cements, in addition to those reported on p. 73.

Those published by Grayson[1] refer to cementation carried out in the usual boxes, on steel cylinders about 30 mm. in diameter and having the following composition:

Carbon	0.170 percent.
Manganese	0.704 percent.
Silicon	0.056 percent.
Sulphur	0.060 percent.
Phosphorus	0.047 percent.

The cements used were: 1. Ground bones. 2. A cement placed on the market under the name of "Brown Scintilla." 3. Ignited leather. 4. Caron's cement (60 wood charcoal and 40 barium carbonate), and called by the author "Hardenite." The following table contains the results of their analysis.

	Designations of the cement			
	Bone	"Brown scintilla"	Ignited leather	"Hardenite"
Carbon (fixed at 1000° C.)	8.0	11.0	69.0	44.0
Volatile matter and hydrocarbons.	26.5	53.0	15.2	14.1
Nitrogen	3.5	3.0	3.8	0.9
Ash	60.0	23.5	3.5	37.5
Sulphur	0.1	0.45	0.55	traces
Moisture	2.0	9.0	8.0	3.5
Total	100.1	99.95	100.05	100.0
	Analyses of the ash			
Phosphoric acid	16.0%	2.0%	0.10%	Traces
There were also present	Alumina Lime Ammonia	Alumina Lime Ammonia Soda Silica Carbonates	Alumina Lime Iron Silica	Barium Iron (traces) Silica Carbonates

The variations in the concentration of the carbon in the cemented zones were determined with great care by removing, on the lathe, from the ce-

[1] *The Journal of the Iron and Steel Institute*, 1910, I, pp. 287–302.

mented cylinders some thirty successive co-axial layers each about 0.0625 mm. thick and determining, by combustion and direct weighing, the carbon in each.

The results obtained at various temperatures and prolonging the cementations for different periods of time are collected in the four following diagrams, traced, as usual, by taking abscissas proportional to the distances of the analyzed layers from the external surface and ordinates proportional to the concentration of the carbon in the steel of these layers. The temperatures of cementation were determined simultaneously with a Féry pyrometer and a platinum resistance pyrometer. The author indicates

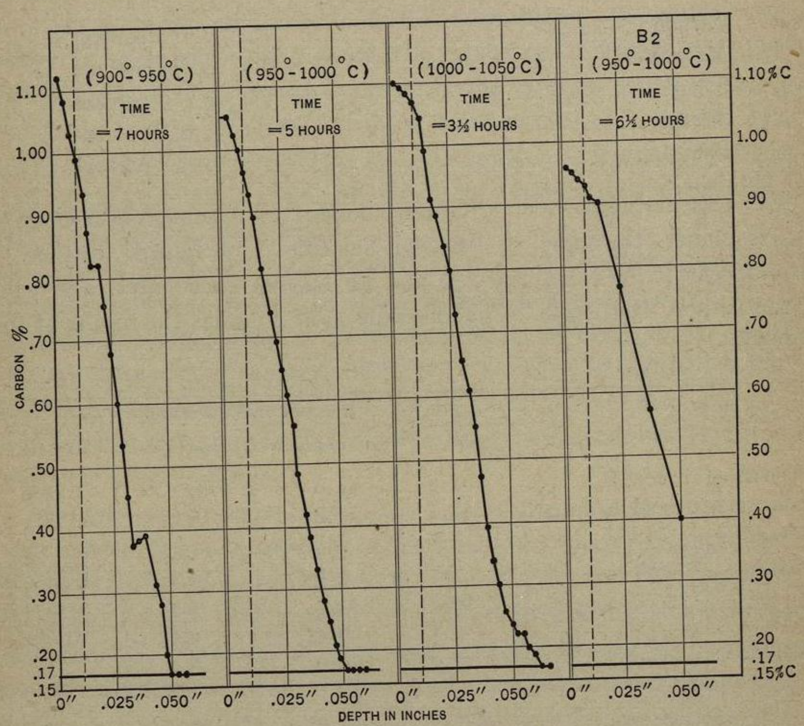

FIG. 116—Diagram 1. "Bone."

only intervals of 50° C. between which the temperature remained during the whole cementation, but adds that the oscillations in the temperature never exceeded 30° C. This insufficient precision in the determination of the temperature and of its oscillations deprives Grayson's experiments of a great part of their practical importance, as results from our previous explanations.

The first diagram (Fig. 116) contains the results of four cementations carried out with the first cement (bone) at the various temperatures indicated in the diagram. The fourth curve refers to a cementation carried out at 950°–1000° C. with cement already used for previous cementation at 950°. As is seen, the cement already used, and deprived therefore of the greater

part of the volatile organic substances which it first contained, has become more "gradual," giving cemented zones of lower carbon content. This is an example of the fact, already stated, that cements containing volatile organic substances (hydrocarbons, etc.) are among the most "sudden" cements.

The second diagram (Fig. 117) contains the results of four cementations carried out with the second cement ("Brown Scintilla") at the various temperatures indicated in the diagram. As is seen, this is a case of a very

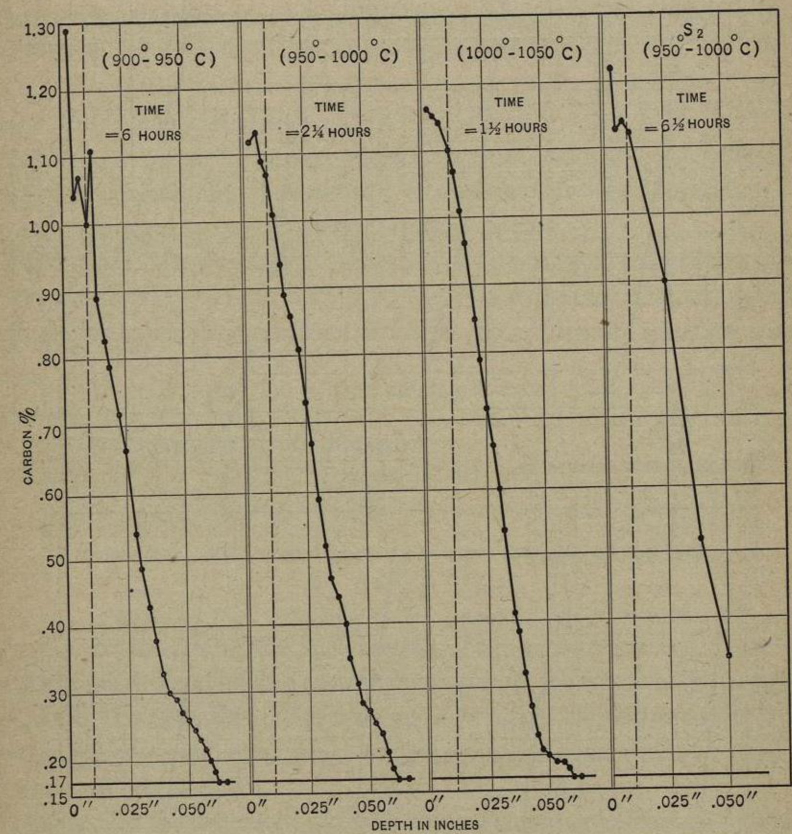

FIG. 117—Diagram 2. "Brown Scintilla."

"sudden" and very irregular cement. The four curves of the diagram offer a new confirmation of the irregularity and uncertainty of the results obtained with most of the solid cements in common use.

The third diagram (Fig. 118) contains the results of four cementations with ignited leather. As is seen, this also is a very irregular but less "sudden" cement than the preceding. It is very easily exhausted, as follows from the fourth curve, which refers to cementation with cement previously used once.

Finally, the fourth diagram (Fig. 119) shows cementation curves ob-

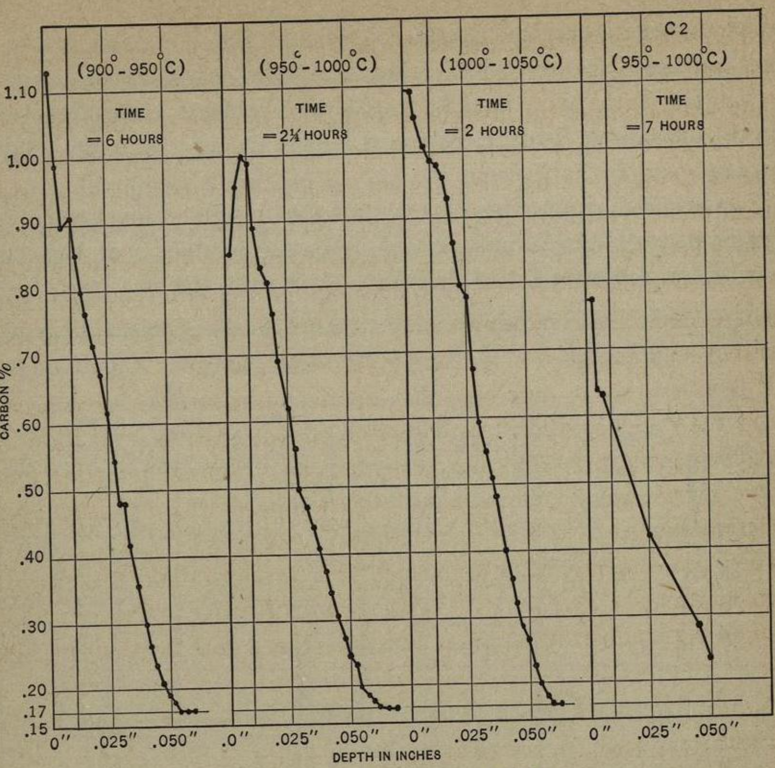

FIG. 118.—Diagram 3. "C."

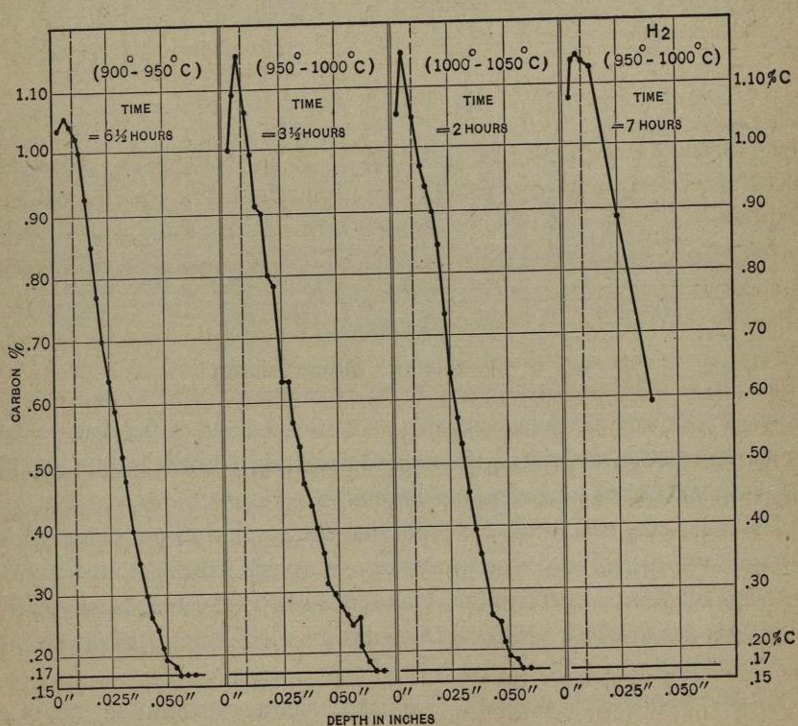

FIG. 119.—Diagram 4. "H."

tained at various temperatures with the Caron cement (carbon and barium carbonate).

The comparison of the first curve of the fourth diagram with the second and third curves shows clearly (especially if we take into account the length of the cementations) that this cement is more "sudden" the higher the temperature of cementation.

The fourth curve, corresponding to cementation carried out with cement already used previously for another cementation, confirms the fact that this cement does not become appreciably exhausted, or, rather, that it is regenerated spontaneously on remaining exposed to the air.

It is interesting to note here that the data just reported show that all four of the cements studied by Grayson, chosen by him from those considered best by "experts," furnish cemented zones containing marked hypereutectic layers and therefore subject to the phenomena of brittleness and exfoliation alluded to in the first part of this volume.

They also evidently confirm the fact, well known to all practitioners, that in cementations carried out with solid cements it is not practically possible to obtain with sufficient exactness a predetermined definite result by simply

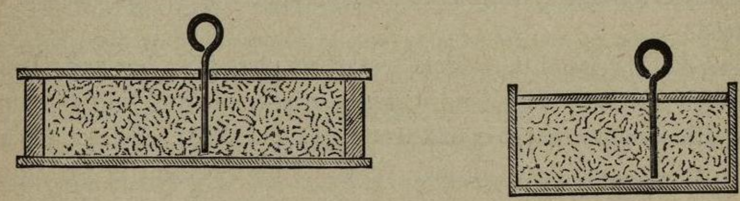

FIG. 120.

fixing the conditions of the cementation, such as temperature, time, etc. Hence the necessity of having means for controlling the course of the cementation *during* the operation. Such means is furnished by the so-called "*regulator test pieces*" of soft steel which are placed in the cementation boxes with the pieces to be cemented.

Usually, for the control of ordinary thin cementations (from 1 to 3 mm.), these test pieces are cylindrical bars 7–8 mm. in diameter, bent at one end into a hook. For the control of cementations of medium or great depth it is necessary to use bars of greater diameter.

The test pieces are introduced with their straight end in the cementation boxes, through holes having 1 to 2 mm. greater diameter. The arrangement of the test pieces in the cementation boxes is represented schematically in Fig. 120. Usually several test pieces are placed in every box and are removed, by means of a hooked rod, one at a time at definite intervals of time. Usually the examination of the test pieces is made by quenching them in water, breaking them near the end which was immersed in the cement and observing the surface of fracture. A more precise examination can be made by allowing the test piece to cool slowly, cutting it normally to the axis 1 to 2 cm. from the end which was immersed in the cement, polishing the section rapidly and etching it for some seconds with a 5% alcoholic solution of picric acid. On placing the section thus prepared in such a way that it reflects light toward the observer, and observing it with the naked eye or, better, with a simple lens, the "structure" of the zone is clearly seen, and from the presence and disposition of the needles of cementite, the masses of compact pearlite and the veins of ferrite, it is easy, for any one who has had some experience, to draw very precise conclusions as to the maximum concentration and as to the distribution of the carbon in the cemented zones, and hence as to the course of the cementation. This method also furnishes much more precise data than the examination of the surfaces of fracture of the hardened test piece as to the really *useful* depth of the cemented zone.

The examination of the polished and etched regulator test piece can furnish much more precise results when it is carried out with the microscope. This is possible, usually, only in plants of a certain size, having at their disposal a metallographic equipment. Moreover, the microscopical examination requires much more careful polishing of the surface to be examined.

Instead of the use of the various test pieces placed in a box and examined successively, Grenet[1] holds (and daily experience confirms fully the correctness of this opinion) that it is sufficient to place a single regulator test piece in each cementation box. In fact, when a known cement is used and the temperature of the furnace is tested from time to time (for example, by means of Seger cones), it is possible to predict with some approximation the time necessary to obtain the desired result; in ordinary cases and for the simplest and best-known cements, this approximation may be considered as being to about 30%. Suppose the regulator test piece to be removed and examined after about two-thirds of the time supposed necessary has passed; if the cementation has proceeded *normally*, the state of the test piece will be that which experience indicates corresponds to two-thirds of the operation. In this case the operation will be completed in the time predicted. If the cementation has proceeded with the *maximum rapidity*, the test pieces will be in the state corresponding to the final result required, and in this case the cementation is immediately interrupted. In all intermediate cases and in those in which the cementation has proceeded with exceptional slowness, the examination of the test pieces after two-thirds of the time supposed to be necessary will give sufficient data for an expert observer to be able to judge satisfactorily how much longer the cementation must still be carried on to obtain the desired result. In other words, the test pieces used in the way

[1] Grenet, *Trempe, recuit, cémentation, et conditions d'emploi des aciers* (Paris, Béranger, 1911).

just referred to serve as indicators of the conditions under which the cementation is really proceeding.

When the cementation boxes have large dimensions, Grenet advises the introduction of several test pieces at various points, and their removal all at once, so as to judge of the real course of the cementation in the various parts of the box.

Besides the regulator specimens just referred to, it is necessary, especially in cementations with solid cements, where the results are least certain, to place at various points of the box, near the objects to be cemented and similarly surrounded by the cement, "verifying specimens" (the so-called "*spies*"), usually consisting of cylinders of soft steel 10 to 15 mm. in diameter. Still more exact data are obtained by using "*spies*" made of the same steel as the pieces which are being cemented.

The examination of the fracture surfaces of these test pieces, removed from the boxes at the same time as the cemented pieces, and quenched together with them, while it constitutes a good guarantee of the satisfactory success of the operation, furnishes useful indications for modifying the conduct of succeeding operations so as to keep on improving the results.

As regards the cost of cementation carried out in boxes with solid cements, it is impossible to give figures of any general value, because the possible conditions of operation vary within too wide limits, either as to cost of the cement, consumption of fuel, consumption of boxes, etc. Moreover, often a small modification in the manner of carrying out a given operation (for example, the charging of the boxes in the furnace, the manner of allowing the boxes to cool, etc.) may change considerably the cost of the cementation.

If we wish to cite some approximately limiting figures, we may consider that the *complete* manufacturing cost (including, that is, interest and depreciation charges on the equipment, labor, general expenses, etc.) for the ordinary cementation of machine parts, carried out in boxes, varies in different works from a *minimum* of 20 centesimi (4 cents) to a *maximum* of 90 centesimi (18 cents) per kilogram of cemented pieces. (1.8 to 8.2 cents per pound.)

Finally, it is necessary to refer here briefly to another subject of practical importance; *viz.*, the protection of parts of the steel objects not intended to be cemented, or which should be cemented only slightly. The directions for this, for cementation carried out with solid cement, hold, in general, also for cementation with liquid, gaseous or mixed cements.

When solid cements are used, the intensity of the cementation can be greatly reduced or even stopped in the desired parts of the steel objects by covering the parts with a more or less thick layer of asbestos fiber. In the majority of cases, and especially when cements are used which, as the result of the high temperature, evolve carburizing gases, as, for example, Caron's cement, the protection afforded by asbestos is insufficient. In these cases more effective protection is obtained by refractory clay, mixed with a little