CHAPTER IV

METHODS FOR CONTROL OF CEMENTATION

The technical methods used for proper conduct of cementation do not, in general, differ essentially from those which are used for the control of the majority of the other processes in the metallurgy of iron.

In this chapter I propose to briefly pass in review some of these methods, stopping only to indicate some details in those cases where the application of a definite method to the control of the processes of cementation or of their products must be made according to special circumstances.

In the technology of cementation it is necessary, first of all, to exercise rigorous control over the raw materials; and then it is necessary to control with precision the temperatures at which the various processes are effected. Excepting in special cases, it is also necessary to follow the course of the carburization during the cementation and then to control it in the finished product. Finally, it is also necessary to make sure that the cemented product has really acquired the required properties after it has undergone the various treatments to which it is subjected after cementation.

§ 1. CONTROL OF THE RAW MATERIALS

The general methods for chemical and mechanical control of cementation steels naturally differ in no way from those followed in general for the control of steels intended for varied uses. Therefore, on these methods it is desirable to dwell only briefly.

There are, however, two points in the control of the steels used as raw materials for the manufacture of machine parts cemented superficially which assume considerable importance. First of all, it is absolutely essential for the success of the cementation that the steel used should be throughout its whole mass as homogeneous as possible.

It is easy to understand how this condition is considerably more important in a steel which is to be cemented and used directly after the cementation, without undergoing a further fusion, than in any other case. In fact, in a steel which is to be used directly as furnished by fusion, the heterogeneities in composition remain such as they were in the crude piece, but in a steel which, before being machined, has undergone heat mechanical treatments (forging, rolling, etc.) or thermal treatments (quenching, annealing, tempering, etc.) the heterogeneities in composition are generally diminished, and at any rate

they are certainly not increased. On the other hand the effects of the cementation (and especially the depth of the cemented zone, the concentration of the carbon contained in it, etc.) vary to a very marked extent with variations in the original composition of the steel subjected to the cementation, so that, to the heterogeneities pre-existing in the steel, are added those which are caused by the different way in which the cementation proceeds in the parts where the composition of the steel is different. A second fact is the presence of veins of slag in the mass of the steel which may give most defective cemented pieces from steel of good mechanical properties.

It is well known, in fact, that small quantities of slag contained in the body of a rolled or forged steel may not exercise a deleterious effect on the various mechanical properties of this steel, and especially on the resistance to tension and to bending when the tension or bending test pieces are taken "longitudinally" or with their major axis parallel to the direction of the lamination. When, however, this same steel is subjected to cementation, the smallest grains of slag become (as we have already seen) centers of "blisters" more or less large according to the nature of the slag and to the conditions under which the cementation was carried out, but always such as to harm the good mechanical properties of the steel to an extent enormously greater than the effect of the original slag on the original steel.

We therefore see clearly the special importance of the examination of the homogeneity of the metal used, and of the greater or lesser proportion of slag contained in it.

Valuable information on this head is afforded by the macroscopic and microscopic investigation of sections of the steel, polished and etched with suitable reagents.

We must assume these tests to be well known, and it is superfluous to enter here into details.

We will add here, as a simple concrete example, some numerical data which will serve as an approximate indication of the limits within which, in general, it is desirable to keep the data of the chemical and mechanical control. Following are some of the conditions established by Guillet for the standard specifications of the "De Dion-Bouton" works, which, as is known, are among the few automobile factories which have organized a serious control of their materials. I take the following data from the interesting memoir published last year by Guillet in the *Gênie Civil.*[1]

1. *Ordinary Rolled Cementation Steel.*—Chemical characteristics:

Manganese	not over	0.40 percent.
Sulphur	not over	0.04 percent.
Phosphorus	not over	0.05 percent.
Carbon	from	0.05 to 0.10 percent.

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[1] *Le Gênie Civil*, 1911, Vol. LIX, Nos. 8–14.

Mechanical characteristics:
(*a*) On metal annealed at 900° C.

Tensile strength	= 37 kg. per sq. mm. (±3)[1] (53,000 lb./sq. in. ±4,000)
Elongation, not less than	30 percent. (−2)
Contraction of area, not less than	70 percent. (−5 when *T.S.* > 38)
Tensile strength + elongation, not less than.	67 (kg. + percent.)
Hardness (Brinell)	= 110 (±10)

(*b*) On metal hardened in air at 900°–925° C.:
Resistance to shock (ρ):

Longitudinally, on small Charpy test piece	18 or over
id., Mesnager test piece	25 or over
Transversely, on small Charpy test piece	13 or over
id., Mesnager test piece	20 or over

2. *Nickel Cementation Steel.*—Chemical characteristics:

Nickel, not less than	2.0 percent. (−0.2)
Manganese, not over	0.40 percent.
Sulphur, not over	0.04 percent.
Phosphorus, not over	0.05 percent.

Mechanical characteristics:
(*a*) On metal annealed at 850° C.:

Tensile strength	= 41 kg./sq. mm. (±3) (58,500 lb./sq. in. ±4000)
Elongation, over	28 percent. (−2)
Contraction of area, not less than	70 percent. (−5)
Tensile strength + elongation, not less than	69 (kg. + per cent.)
Hardness (Brinell)	= 120 (±10)

(*b*) On metal hardened in air from 900°–925° C.:
Resistance to shock (ρ):

Longitudinally, on small Charpy test piece	20 or over
id., Mesnager test piece	30 or over
Transversely, on small Charpy test piece	15 or over
id., Mesnager test piece	25 or over

(*c*) On metal quenched in water at 900° C.:

Tensile strength, under	70 kg. sq. mm. (100,000 lb./sq. in.)
Elongation, over	15 per cent.

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[1] The values in parentheses indicate the tolerances allowed.

3. *Chromium-nickel Cementation Steel* (*First Class*).—Chemical characteristics:

Nickel	= 2.5 percent. (±0.5)
Chromium	= 0.60 percent. (±0.3)
Manganese	= 0.40 percent. or less
Sulphur	= 0.04 percent. or less
Phosphorus	= 0.05 percent. or less

Mechanical characteristics:
(*a*) Metal annealed at 850° C.:

Tensile strength	= 65 kg. (±5) (93,000 lb./sq. in. ± 7,000)
Elongation	= 20 percent. (−2) or over
Contraction of area	= 55 percent. (−3) or over
Tensile strength + elongation	= 85 (kg. + percent.) or over
Hardness (Brinell)	= 170 (± 20)

(*b*) Metal hardened in oil at 850° C. and annealed at 600° C.:

Tensile strength	= 80 kg./sq. mm. (±5) (114,000 lb./ sq. in., ±7,000)
Elongation	14 percent. (−2) or over
Contraction of area	35 percent. (−3) or over
Tensile strength + elongation	94 (kg. + percent.) or over
Hardness (Brinnell)	= 225 (±25)

Resistance to shock (ρ):

Longitudinally, on small Charpy test piece.	12 . or over
id., Mesnager test piece	15 . or over
Transversely, on small Charpy test piece...	8 . or over
id., Mesnager test piece	10 . or over

Besides these, which represent the types usually employed, others of different compositions find quite wide application at present.

The semi-hard steels with 0.3% to 0.4% (and sometimes up to 0.55) of carbon are used as cementation steels in some special cases (for example, for punches, moulds, frogs, etc.); the steels of high nickel content, brought into practise by Guillet (see p. 52); the vanadium steels, which are said to be largely used to-day by the American automobile factories;[1] the

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[1] On the real value and on the mechanical properties of the vanadium cementation steels, there have thus far been published no data which are complete or precise. For simple information I report the data in the following table, taken from a Note of Schindler (see *Journ. of the Iron and Steel Institute*, 1908, I, p. 179) on the use of chromium-vanadium steels in cemented machine pieces. The numbers refer to pieces cemented to a depth of

chromium-nickel steels for armor; and still many others. Naturally, I can not stop to describe here the conditions of control of these various types of cementation special steels. The chemical and mechanical conditions which they must satisfy vary within very wide limits. It may, in fact, be held that all these conditions must be studied separately, in turn, whenever it is desired to obtain definite special results. In all the other ordinary cases it is preferable to use types of steels analogous to those whose characteristics are given above, since precise and well-defined rules can be applied for their cementation.

A test of exclusively *preliminary* character, to which it is customary in practice to subject every cementation steel, consists in annealing a specimen, cutting it and breaking it. If the surface of fracture thus obtained has not a fibrous appearance, it is quite difficult for the steel examined to possess one of the properties essential for its acceptance—the faculty of being "regenerated" as the result of hardening. The very great technical importance of this property is evident.

§ 2. CONTROL OF THE TEMPERATURES OF CEMENTATION AND QUENCHING

We have already seen that the temperature at which the cementation is effected influences very intensely the velocity of the cementation, the maximum concentration reached by the carbon in the cemented zone, and also the "distribution" of the carbon in this zone. This may cause two cementations, carried out at two temperatures differing from each other only by a few degrees, to furnish products possessing profoundly different characteristics. The necessity of knowing with precision and of being able to regulate with the greatest certainty the temperature at which the cementation is effected is therefore evident. The necessity of being able to know exactly at any moment the temperature at which the cementation is carried out makes itself especially felt when this cementation is conducted at a temperature varying more or less rapidly between definite limits, instead of at a constant temperature, as is usually done. This, for example, is done (as we have seen on pp. 159–166) when advantage is taken of the oscillations in the temperature of the cementation to raise the concentration of the carbon in the cemented zones. We have seen that this procedure is followed especially when using "mixed" cements, and we shall see shortly that precisely with these cements a frequent measurement of the temperature is easiest.

The pyrometers which are used for the measurement of the temperature of cementation do not differ from those which are used for the control of the other metallurgical processes, except that the special conditions in the majority of the cementation processes render the use of some types of pyrometers by far preferable to other types which otherwise might appear more advantageous. Moreover, the pyrometric measurements in the cementation apparatus will not have a precise significance and will not furnish useful data unless carried out under certain definite conditions, depending on the cement used and on the way of conducting the operation. In fact, we have seen that the greater part of the solid cements used in industry are very bad conductors of heat, so that quite a long time is always necessary for complete temperature equilibrium to be reached throughout the mass in the cementation boxes;[1] therefore the measurement of the external temperature of the cementation boxes, even if carried out at frequent intervals during the heating, cannot furnish precise data as to the *true* temperature of the cementation, or the temperature of the region of contact between the surface of the steel objects and the cement. To get that, we must know the law of propagation of heat in the mass which fills the boxes. But it is evident that the velocity of the propagation of heat from one point to another of the mass under consideration is maximum when the two points form part of a same piece of steel, minimum when between the two points is interposed the cement only, while, when between the two points considered are interposed alternating masses of steel and of cement, this velocity has an intermediate value between these two extremes and is greater the greater the proportion of the steel as compared with that of the cement.

It is therefore evident that the propagation of heat in a charged box will in general be irregular and will depend, even more than on the thermal conductivity of the cement, on the quantity, the form and the position of the steel pieces contained in it. So that, to deduce with precision from the measurements (even if repeated frequently) of the external temperature of the boxes the temperature reached at various times in the different regions of the charge, the measurement of the thermal conductivity of the cement alone will certainly not suffice.

A sufficiently precise deduction of this kind can be made only in case the same pieces of steel are always to be cemented, and under identical conditions. In this case alone is it possible to make once for all a direct experimental

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one-twentieth of an inch. The mechanical tests—only statical—were made on the metal of the "heart" of the pieces, after having removed the cemented zones on the wheel.

	Common carbon soft steel	Chromium-vanadium steel
Limit of elasticity (tons per sq. in.).......	20.42	34.13
Breaking load (tons per sq. in.)...........	32.36	45.75
Elongation (on 2 in.)....................	34.5%	22.0%
Contraction............................	54.2%	61.6%

In the note cited above, neither the composition of the two steels nor the heat treatment to which they were subjected after the cementation are indicated precisely.

The author holds that his chromium-vanadium steel is especially adapted to making cemented machine parts designed to bear very variable forces.

[1] See, for example, the data reported on pp. 314–315.

determination of the velocity of propagation of heat in the mass constituting the charge of the boxes and then regulate, on the basis of the results thus obtained, the length of the successive cementations carried out under identical conditions, either as regards the method of making the charge, the raw materials used, the operation of the furnace, or, finally, the dimensions and the form of the boxes used. In any other case it would be illusory to consider that a procedure of the kind just indicated can furnish data of any exactness on the propagation of the heat in the mass constituting the charge of the boxes, and only when it is not necessary to obtain perfectly definite results can this procedure be used, even though complete identity between the conditions under which the operation is effected and those under which the test was carried out is not realized.

When the conditions which I have indicated above are not realized, it is not possible to obtain with certainty and precision pre-established results from cementations carried out in the usual cementation boxes charged cold, except by working in such a way as to be able to determine at any instant the temperature in the various regions of the mass constituting the charge of the boxes.

This last condition may be realized quite well by placing a tube of iron along an axis of symmetry of every cementation box in such a way that the two open ends of the tube pass tightly through the walls of the box and project outside of it.

A thermo-electric couple, whose junction, suitably insulated, is placed successively at various points of the tube, permits then of determining the temperatures of the various "strata" of the mass, in each of which, for reasons of symmetry, the temperature must be nearly constant. Nevertheless, the placing of such tubes is not always possible; as happens, for example, when pieces of steel of considerable dimensions are to be placed in the boxes. And in any case the joints between the tube and the walls of the boxes very quickly become loose, giving admission to air, which is very harmful to the success of the cementation. This results in greatly shortening the normally brief "life" of the cementation boxes, and therefore in enormously aggravating the most serious disadvantage of the processes of cementation using boxes.

Nor can the theoretically perfectly logical and very ingenious solution proposed by Grenet[1] be regarded as practical. It consists in "heating the boxes in a continuous furnace whose temperature rises sufficiently slowly so that the boxes may be considered practically to be in temperature equilibrium with the furnace." Grenet proposes to obtain such a result by means of furnaces of an elongated form, whose ends are kept at a temperature considerably lower than that of the operation at which the cementation is to be effected; the boxes would be introduced into the furnaces successively "in

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[1] L. Grenet, *Trempe, recuit, cémentation et conditions d'emploi des aciers* (Paris, Béranger, 1911, p. 214).

series" from these ends, and gradually pushed toward the hotter parts of the furnace.[1]

Then "the law of the cementation would be deduced from the velocity of the circulation of the boxes and from the law of the temperature of the furnace."

But Grenet himself recognizes that "this system would have the disadvantage of increasing the duration of the cementation, and, moreover, like all apparatus for continuous operation, such a furnace would not lend itself to enormous variations in the cementation. If in the same furnace could be placed two series of boxes, which were made to proceed with different velocities, there could be obtained two thicknesses of cementation, which in many cases would be sufficient." It is evident that such a procedure can not be applied in the very great majority of cases.

From what has been just said, and from the data reported in the preceding chapters, it is easy to understand how, in almost all of the cases which present themselves in the technology of the processes of cementation based on the use of solid cements in the boxes, a *precise* and *truly efficacious* control of the temperatures of cementation is practically impossible.

Ordinarily, makers of machine parts limit themselves to measuring repeatedly the external temperature of the boxes during the entire operation and from the results of such measurements it is generally held, in truth with a certain ingenuousness, that it is possible to deduce, "with the aid of long practice," some useful indications as to the course of the heating within the boxes.

The pyrometers most frequently employed for this use are the Le Chatelier thermo-electric couple and Féry's optical pyrometer.[2]

The use of these apparatus is now very extensive in all branches of metallurgical technology, and is to-day familiar to every one;[3] we limit ourselves to

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[1] It is well known that an analogous procedure is used to obtain the "gradual" heating of steel objects of large dimensions which are to be hardened "in series;" for example, for the hardening of projectiles of large caliber.

[2] In some works Seger cones are used, placed at various points of the laboratory of the furnace. Usually, cones of two series are employed simultaneously; those melting at a lower temperature (usually 25° C. below the normal temperature of the cementation) are introduced from time to time to determine if the temperature has reached the minimum required, while those melting at a higher temperature (about 25° C. above the normal temperature of the cementation) are left constantly in the furnace to make sure that the temperature in it never exceeds the pre-established maximum. The insufficient precision and the slight certainty with which temperatures can be measured by means of the Seger cones render absolutely inadvisable the method of control just referred to.

More precise results are obtained with the Siemens calorimetric pyrometer, but every measurement with this apparatus requires some delicate manipulation which renders its frequent use not very convenient.

[3] On apparatus for measurement of high temperatures consult Le Chatelier and Boudouard, *Mesure des températures élevées;* Roberts-Austen, *Introduction to the Study of Metallurgy;* C. R. Darling, *A Practical] Treatise on the Measurement of High Temperatures*, London, 1911.

referring to the way they are generally used for the measurement of the temperature of the cementation boxes.

In using the Féry pyrometer (direct vision or telescope) it suffices to point it directly at the wall of one of the boxes, and it is desirable that the apparatus should be focussed on only a single one of the boxes, so as to avoid the possibility that in the space between the two boxes might appear a section of the wall of the furnace hotter or cooler than the boxes themselves. The same observations hold for the use of other optical pyrometers, such as that of Le Chatelier, Wanner, etc.

When it is desired to make direct precise measurements with the Le Chatelier thermo-electric couple (platinum against rhodium-platinum alloy with 10% rhodium), "spies" are used, consisting of cubes of soft steel of various dimensions, according to the dimensions of the boxes and of the laboratory of the furnace. Usually "spies" of 50 to 80 mm. (2 to 3.2 inches) to the side are used. The cube is traversed by a hole of sufficient diameter so that the end of the iron tube forming the guard of the thermo-electric couple can be introduced into it. Usually a "spy" is placed on every box, so arranged that the hole is directed toward the door of the furnace. In this way it is easy to introduce successively the end of the couple into the various "spies," and to thus follow accurately the variations in the external temperature of each box.

It is well known that many makers place on the market thermo-electric couples already mounted in iron guards filled with insulating refractory material and furnished with a handle with binding screws to which are fastened the copper wires which lead to the galvanometer. But experience shows that these guards are too "perfect" for practical uses. First of all, the thermo-electric couple is fixed in them too rigidly, so that a slight bending of the guard almost always results in wrenching off of the wires of the couple.

Moreover, the replacement of the external iron tube, also carefully fixed to the other parts, is difficult, so that in practice where this substitution is necessary frequently, especially where the instrument is used in an oxidizing atmosphere, it is equivalent to remaking the whole apparatus. Finally, the necessity of not having to change too frequently the various parts of a complicated and delicately set up apparatus entails having to make either the iron guard tube or the refractory insulating material quite thick, and for this reason the couples thus mounted follow slowly and with considerable lag the variations in the temperature of the furnace.

For all these reasons it is better to use a much simpler protecting tube, formed of an iron tube (usually of an external diameter of 15 to 20 mm. (0.6 to 0.8 inch) and 1 to 3 mm. (0.04 to 0.12 in.) thick) in which is placed a porcelain tube, closed at the end corresponding to the closed end of the iron tube. In the porcelain tube, whose external diameter must be 3 to 5 mm. (0.14 to 0.20 in.) less than the internal diameter of the iron tube, the thermo-electric couple is placed, one element being insulated by making it pass through a series of fine porcelain tubes 3 to 4 mm. (0.09 to 0.16 in.) external diameter. The ends of the couple which issue from the tube are fixed to two binding screws carried on an insulating ring, which is attached with a simple pressure screw to a point of the protecting tube itself; to these binding screws are fastened the two copper wires which lead to the galvanometer. In this way all the parts of the apparatus are completely independent of each other, so that each one of them (and especially the iron tube) may be easily and rapidly replaced when it has deteriorated. Moreover, any bending, even considerable, of the iron tube has no other effect than that of breaking, often at various points, the enclosed porcelain tube, but the various pieces of the latter continue acting as insulators, and in any case the thermo-electric couple does not suffer at all. Moreover, the thermal insulation of the couple is thus reduced to a minimum.

The measurement of the real temperature of the cementation is much easier and more precise when liquid cements are used, for the convection currents enormously facilitate rapid attainment of temperature equilibrium throughout the mass of the fused cement and the steel pieces immersed in it.

The form of the furnaces usually employed for cementation with liquid cements renders very suitable the use of a protecting tube bent to a right angle for the protection of the thermo-electric couple. Such a form of guard tube, in fact, has the advantage of bringing the binding screws constituting the "cold junction" of the couple outside of the space immediately above the furnace, a space where the hot and corrosive vapors which are evolved from the fused salt bath collect. With a straight guard tube the binding screws would necessarily be in that situation. Moreover, it is evident that a straight guard, having to be very long to carry the cold junction binding screws to a sufficient distance from the bath, is in the way in the operations of charging and discharging the pieces in the cementation bath; operations which must necessarily be made from the upper surface of the bath.

There are on the market thermo-electric couples mounted in guard tubes bent to a right angle, but they present, to a still greater degree, the same disadvantages which I have already enumerated for the straight guards.

On the other hand, it is easy to set up a considerably simpler system, analogous to that which I have already described in the case of the straight guard and which presents, notwithstanding the bend at a right angle, the same advantages (and especially the same facility of mounting and dismounting and the same independence of its elements) referred to for the preceding case.

Fig. 153 represents schematically the vertical section of the guard tube for the thermo-electric couple immersed in the cementation bath. The tube with square bend is obtained by removing the greater part of the wall of the straight tube between two generatrices about 90° distant from each other and bending the remaining part O outwardly. It is then easy to mount the couple throughout the whole lower section LB in the same way as I have already indicated for the straight guard by introducing into the iron tube the porcelain tube B and in this the thermo-electric couple, one wire of which is insulated by means of the usual smaller porcelain tubes. At E the couple is bent, the two wires being insulated with porcelain beads, and made to pass into the horizontal arm of the guard, being insulated with two glass tubes. The ends of the two wires of the couple are fastened in the usual way to the two binding screws H and G. At the various joints a little asbestos fiber can be introduced to better keep in place the different pieces.

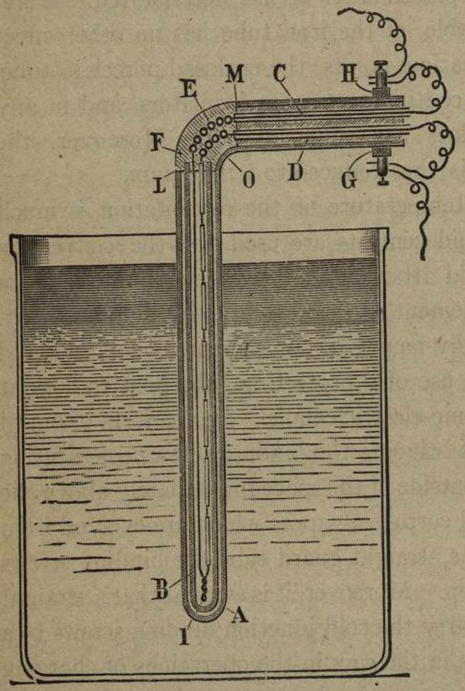

FIG. 153.

This system of mounting the couple is extremely simple and cheap and that which in practice gives the best results and guarantees a longer life of the couple.

For the control of the temperatures in cementation with liquid cements, usually no other pyrometer than the thermo-electric couple is employed.

In cementation with gaseous cements the measurement of the temperature made *directly* on the pieces subjected to the treatment, while it would be easier because the pieces are not surrounded by any solid substance, is hindered, on the other hand, by the necessity of keeping the cementation chamber perfectly closed, so as to avoid entrance of the air or of the gases in the laboratory of the furnace. This necessity excludes, first of all, the possibility of using an optical pyrometer for the measurement of the temperatures *in the interior* of the cementation chamber, and renders it necessary, for making such a measurement with a thermo-electric couple, to arrange one or more metallic guard tubes *soldered* to the walls of the chamber, and placed in such a way that they reach the point of the chamber at which the exact measurement of the temperature is most important. The inside of these guards must communicate with the exterior by means of an opening through which the two insulated wires constituting the thermo-electric couple can pass, but must in no way communicate with the interior of the cementation chamber. If such a communication should exist, not only might the gases of the laboratory of the furnace or of the outside atmosphere penetrate into the cementation chamber, mixing with the carburizing gas and weakening its carburizing efficacy, but the metal thermo-electric couple, coming in contact with the carburizing gases, would be gradually altered, becoming brittle and ceasing to give exact temperature indications.

The difficulty of realizing in practice the conditions just referred to, especially when the cementation chamber is movable,[1] results in the majority of cases in only the *external* temperature of the cementation chamber being measured. In these cases the measurement of the temperature is made according to the same rules as hold for the measurement of the temperature of the ordinary cementation boxes, except that in the case of the gaseous cement the absence of a mass acting as an excellent thermal insulator (such as that constituted for the most part by the solid cements) results in the equilibrium between the external temperature and that within the cementation chamber being reached in a considerably shorter time, so that the errors arising from the imperfect knowledge of the law of the propagation of heat from the periphery to the center of the mass contained in the cementation chambers are, all other conditions being equal, markedly diminished.

When the cementation is carried out with mixed cements (solid and gaseous) under the conditions already indicated in detail, the direct measurement of the *true* temperature of the cementation can be effected in a considerably easier and more certain way than in the cases in which the solid cements or the gaseous cements are used separately. And this for the following essential reasons:

1. Contrary to the ordinary solid cements, the solid constituent of the mixed cement (usually "granular" wood charcoal) forms a mobile mass endowed with very slight consistency, and these qualities are in no way diminished during its use, for the granular carbon of the mixed cement is simply "poured" like a liquid on the pieces to be cemented and it is in no wise necessary to compress it around them to insure contact with the surface of the steel. The result of this is that it is easy to introduce the iron tube containing the suitably insulated thermo-electric couple *at any point* of the mass of granular carbon and thus to measure the true temperature of cementation without the necessity of fixing any special tube or other article into the cementation chamber.

2. Contrary to what happens in the use of the ordinary gaseous cements, the gaseous constituent of the mixed cement (usually a mixture of carbon monoxide and of carbon dioxide) does not circulate freely in the spaces between the various pieces of steel in the cementation chamber; it is, on the contrary, forced to circulate in the very small interstices which separate the grains of carbon, permeating the mass of this carbon. Under such conditions, the carburizing gases encounter appreciable friction in the mass

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[1] As, for example, in the Machlet furnaces, referred to on pp. 287-293.

through which they have to circulate, and they escape from it only very slowly, even when the external surface of this mass comes in contact with a gas of composition different from that of the gases which permeate it. It follows from this that in cementation carried out with the mixed cements the cover of the cementation chamber can be opened to introduce the pyrometer into the mass within it without the external gases being able to penetrate into it to an appreciable depth and reach the steel pieces. This penetration is also retarded by the ascending current of carburizing gases which circulate slowly in the apparatus.

3. Contrary to practice with the ordinary solid cements, where the charge must be made cold on account of the necessity of gradually charging the steel pieces and the cement, the mixed cements permit of introducing the charge quite hot, so that, up to the beginning of the operation, the temperature is almost uniform throughout the whole charge, and such that the process of carburization begins at once. This fact permits of timing with precision the real period of the cementation for the whole charge, and renders it unnecessary to carry out the measurement of the temperature at more than a few points in the cementation chamber.

It follows that the practical measurement of temperatures in operations carried out with mixed cements approaches those where liquid cements are used rather than those followed for gaseous cements or solid cements. In fact, for the mixed cements also, the best way of effecting control of the temperature consists, as we have seen, in "immersing" the junction of the thermoelectric couple (suitably protected) directly in the mass contained in the cementation chamber.

As regards the control of the temperatures of quenching, there is no need of using special arrangements and apparatus. As for the apparatus designed for the quenching itself, so also for those designed for the control of the temperatures at which it is effected, they do not differ from those which are ordinarily used for the quenching of any other kind of steel objects.

The same observations hold as regards the control of the temperatures of tempering and of annealing of cemented and hardened pieces.

§ 3. CONTROL OF THE COURSE OF THE CARBURIZATION

Only when cements of a simple, perfectly defined and well-known chemical nature are used, and the cementation is carried out under conditions which are well defined and can be continuously controlled with exactness, is it possible to obtain satisfactorily cemented zones of the desired type. We have seen that such a result can be obtained when certain gaseous or mixed cements are used and the temperature of the cementation, the pressure of the carburizing gas, the velocity with which this gas circulates in the cementation chamber, etc., are carefully controlled.

In the majority of cases these exact controls are not practically possible, and a pre-established result can be obtained with certainty only by following closely the carburization of the pieces by means of the frequent examination of one or more test pieces of this steel, placed in the cementation chambers. As to the method of placing the control specimens in the solid cement of the ordinary boxes, sufficient directions have already been given (see p. 275).

In cementation with gaseous cements, the control of the course of the carburization by means of the examination of the test pieces is most difficult in practice, owing to the necessity of opening the cementation chamber during the operation to remove the test pieces, and I have already enumerated in the preceding pages, in connection with the measurement of temperature, the disadvantages of this opening.

Where the cementation is carried out with the liquid or mixed cements, the control is exceedingly easy, for in these cases a rod of steel can, without any inconvenience, be immersed in the cement and then removed for examination as many times as may be considered desirable, without any harm at all to the regular cementation of the other steel objects.

I have already pointed out how the method generally used for the examination of the control specimens, consisting in quenching them, breaking and examining their surface of fracture, can give only uncertain and incomplete results, and this because of two reasons:

1. The peripheral "fine-grained" region which appears on the surface of fracture of a cemented and hardened specimen,[1] and on which the determination of the depth of the cementation is frequently based, in no way corresponds to a region in which the concentration of the carbon exceeds or at least equals a *well-defined* value; this is shown by the fact that a same cemented piece (in which the uniformity and the thickness of the cemented zone have been controlled by precise means, such as chemical analysis or microscopical examination), when quenched under conditions differing only slightly, and broken in different ways (for example, with different velocities of shock) presents in its surface of fracture "fine-grained" peripheral zones of different extents. It is clear, therefore, that the examination of the fracture can furnish a measure of the *depth* of the cementation only to a very rough approximation.[2]

2. The examination of the surface of fracture of a cemented and hardened piece of steel can furnish no indication as to the maximum concentration of the carbon in the cemented zone and, still less, as to the variations in the concentration of the carbon (or the "distribution" of the carbon) in the vari-

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[1] As is well known, for a cemented zone with 0.9% of carbon, obtained in an ordinary soft steel, the temperature of heating best adapted to show the fineness of the "grain" by means of quenching in water is between 750° and 780° C., and varies according to the dimensions of the piece which is hardened, the temperature of the water, etc.

[2] As a confirmation of these assertions, I think it well to copy here some numerical

ous layers of the cemented zone. The knowledge of these last data is often more useful than that of the actual depth reached by the cementation.

From all this follows the necessity of having recourse to more precise means of examination whenever sure and complete data as to the course of the cementation are to be obtained from the examination of the control specimens.

Also, in view of the frequency and the rapidity with which the observations on the control specimens must be made, it is absolutely impossible to have recourse to chemical analysis, especially because it would give complete results only when made on various successive layers of the cemented zone.

Rapid and almost as precise results are given, on the other hand, by the microscopic examination of the cemented control specimens, allowed to cool slowly. This examination, which is always made on a plane section normal to the surface of cementation, presents no difficulty and requires but a few minutes.

The usual reagents used in metallography for etching carbon steels[1] show up very clearly the three constituents, from the relations of which the carbon content of the steel examined can be at once deduced, coloring the pearlite (or, as the case may be, the sorbite) a dark brown, and leaving brilliant the ferrite and the cementite, which are then easily distinguished from each other by the form of their structural elements. Hence, to obtain

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data reported by A. Portevin and H. Berjot (see *Revue de Métallurgie; Mém.*, 1910 pp. 73-74).

Depth of cementation measured with the microscope on non-quenched and polished specimens (mm.)	Depth of cementation measured on the same specimens, quenched and broken (mm.)
0.50	0.45
0.84	0.65
0.90	0.72
1.25	1.10
1.50	1.17
1.92	1.72
2.30	1.65

The corresponding pairs of figures in the two columns refer to the same specimen.

The effect of the conditions of quenching on the measurement of the depth of the cementation based on the examination of the surfaces of fracture may be seen from the following table, the values of which all refer to the same specimen (see Portevin and Berjot, *loc. cit.*).

Condition of execution of measurement	Depth of cementation (mm.)
On non-quenched and polished specimen..............	1.62
On specimen quenched at 700° and broken.............	1.57
On specimen quenched at 800° and broken.............	1.92

[1] The most frequently used of these reagents are a 5% alcoholic solution of picric acid and a 5% solution of nitric acid in amyl alcohol.

precise data as to the concentration of the carbon it is not necessary to extend the polishing until the disappearance of the last striæ, for these do not so mask the structure as to prevent a correct estimation of the relations between the areas occupied in the section by the various constituents. Under these conditions the polishing does not require more than two or three minutes. If we add the time necessary to cut from the control specimen a piece of the size adapted for the metallographic examination, and the few seconds necessary for the microscopic examination, it is seen that for the whole test not more than four to five minutes are required.

The numerous examples which I have reported in the first part of this volume show the precision and the clearness of the data which the metallographic examination of the cemented and non-tempered pieces can furnish, both as to the maximum concentration and as to the distribution of the carbon in the cemented zones. It suffices to use, for this examination, a microscope supplied with an exact micrometric apparatus.

It is necessary to point out, however, that since the deductions from the control specimens have no absolute value if the composition of the steel of which they are made is not identical with that of the objects whose cementation is being controlled, the microscopic examination of the control specimens will cease giving precise and absolute results when various special steels are being cemented. All such steels preserve, after the heating, the martensitic or polyhedric structure of γ-iron. In the majority of these cases, however, the examination of the surface of fracture also does not furnish clear or precise data.

An experienced eye can also obtain satisfactory data of precision as to the depth of the cementation and the concentration and the distribution of the carbon in the cemented zones from a simple examination with the naked eye of the plane sections of the control specimens, polished and etched with the 5% alcoholic solution of picric acid. In the section thus prepared, examined obliquely under an intense light, there appear most clearly, and in strong contrast with the brown areas of the pearlite, the gleaming needles of the cementite and the more extended clear masses of the ferrite. Especially clear to the naked eye appear the eutectic zones, of compact pearlite, and the lines of abrupt junction (corresponding to sudden variations in the concentration of the carbon) between these zones and the contiguous hyper-eutectic or hypo-eutectic zones.

It is clear, however, that a correct estimate of the various concentrations of the carbon and the thicknesses of the differently carburized individual layers can be obtained only by means of the microscope and with the aid of micrometric gratings which permit of determining such small lengths and of measuring with good approximation the areas occupied in the section of the steel by the individual constituents.