§ 4. CONTROL OF THE CEMENTED PRODUCTS

In the greater number of cases the cemented pieces are intended to be used only after quenching, so that almost always, after the control of the course of the carburization with which we have dealt in the preceding section, the cemented piece is not subjected to any direct tests until it has undergone all the further heat treatments designed to make it suitable to be put into use. It is only in exceptional cases that a direct examination of the piece as it issues from the cementation chamber is undertaken.

When having many identical pieces (for example, bolts, dies, small axles, etc.) to be cemented under identical conditions, one is removed from time to time to examine its fracture after quenching, polishing and etching a section, the pieces thus examined become useless and can be considered only as true control specimens proper. The only cases in which a direct control of the result of the cementation on the cemented but not hardened pieces is desirable are those in which a deficiency or an excess in surface hardness in analogous cemented and hardened pieces has been observed, and it is desired to find its cause by separating the control of the effects of the cementation from that of the effects of the quenching. These latter tests, as is well known, depend on the dimensions and on the form of the object under consideration, and they can not, therefore, be controlled with certainty by examining a specimen different in form and dimensions from those of the object dealt with.

If the piece on which it is desired to control the result of the cementation must not be altered, and no part of it can be removed, it is clear that the control can not extend beyond the surface layer of the metal. In this case, the only control possible consists in polishing a more or less extended section of the surface of the object, etching it with one of the usual reagents and examining it under the microscope, so as to determine the carbon content of the surface layer of the object.

If, on the contrary, it is possible to remove from the object which it is desired to examine, without rendering it useless, a piece of sufficient dimensions so that it will include all or part of the thickness of the cemented zone, it is clear that the control of the cementation can be carried out with the methods referred to for control specimens.

The interpretation of the results furnished by the various methods (and especially by the micrographical method) has already been dealt with at length in the first part of this volume, where especial emphasis was placed on the strict relations which exist between the distribution of the carbon in the cemented zones and the phenomena of "exfoliation" which may manifest themselves in these zones after quenching.

The control of the superficial carburization, made directly on the cemented pieces in the manner indicated, may give useful indications where extremely thin cemented zones are dealt with, like those which we have seen can be obtained in the processes of rapid cementation, for example, with fused potassium ferrocyanide. In such cases, in fact, it is not possible to require one rather than another distribution of the carbon in the successive layers of the cemented zone, and the value of the result obtained depends only on the concentration reached by the carbon at the external surface of the cemented piece.

§ 5. CONTROL OF THE CEMENTED AND HARDENED PRODUCTS

The methods for the control of the cemented and quenched products may be collected in two groups. The first of these groups includes the methods whose application renders the piece examined useless, so that these methods can be applied only to a specimen subjected to treatments as nearly identical as possible with those undergone by the pieces which it is desired to control, or to one or more of these pieces themselves when it may seem convenient to prepare and treat a certain number of pieces designed especially to serve as test pieces and therefore to be put out of commission. It is clear that the second procedure, in which the pieces utilized as control specimens are *identical* with the pieces which are really to be used, can furnish considerably more precise indications than that based on the examination of specimens of different form and dimensions, but it is also clear that this procedure can be applied in practice only when it is a question of controlling not very expensive pieces, manufactured and treated in series.

The methods which may be collected in the second group are those which can be applied directly to the cemented and hardened pieces without their being made useless.

Among the methods of the first group, we will recall those designed to verify the effects of the various heat treatments on the mechanical properties of the "core" of the cemented pieces; those designed to verify the course of the variations which the hardness of the steel presents at various depths, the superimposed effects of the cementation and of the hardening; those designed to find the causes of the brittleness of a cemented piece, etc.

To the second group belong the methods designed to determine the mineralogical hardness of the surface of the cemented and hardened piece and to control the efficacy of the means of protection applied to the parts of the steel pieces which are not be be hardened even at the surface; those designed to determine the brittleness of the cemented zone and to furnish approximate indications as to the thickness of this zone; those designed to learn whether the insufficient mineralogical hardness of the surface of the cemented piece is due to defects in cementation or in quenching or to a superficial decarburization manifesting itself during the treatments which followed the cementation, etc.

We have already seen that one of the most serious and most frequent of the disadvantages which manifest themselves in cemented pieces is the brittleness of the internal part, or "core" of these pieces, which the carburizing effect of the cement must not reach.

We have also seen already that, whether the cause of this phenomenon is chemical or whether it lies simply in the prolonged heating at a high temperature to which the steel pieces are subjected during the cementation, we can study out on perfectly rational bases the heat treatments by means of which the brittleness of the core of the cemented pieces can be reduced to a minimum while the maximum hardness is obtained in the peripheral zone.

Recognizing the importance of the result which it is desired to obtain and the delicacy and the precision with which these heat treatments must be conducted, the importance is evident of carrying out an exact control to find with certainty if there have really been obtained the mechanical properties which it was desired to impart to the "core" of the cemented pieces by these treatments.

For the control of the tenacity of the metal constituting the core of a cemented piece, there exists no method which permits of making the test without rendering useless the piece examined.

The simplest, but not sure, means of judging of the tenacity of the core of a cemented piece consists in breaking it and examining the appearance of the surface of fracture.

It is well known that a brittle soft steel presents, under such conditions, a "grained" surface of fracture, while for a tough steel this surface has the characteristic appearance usually designated by the term "fibrous" or "nerve structure."

A first cause of the insufficiency of this method of control lies in the fact that the results which can be obtained by it depend only on the personal judgment of the observer, and can not be represented in any way by means of figures.

But there is another fact which proves even more the imperfection of the method just referred to, even when we do not take into account the errors which may result from an inexact estimate of the observer; the appearance of the surface of fracture varies to a very marked degree with variations in the way in which the specimen is broken. Thus, it is easy to observe that the fracture of a specimen (treated in a perfectly homogeneous way) at various points near to each other presents a different appearance according to the way in which the fracture is produced and according to the direction of the surface of fracture. In general, it may be stated that a fracture produced by applying a bending force increasing gradually and slowly, or by applying a series of successive forces, tends to increase the "fibrous" structure, while a surface obtained by suddenly applying a very strong force (dry blow) tends, in general, toward a "grained" structure.

Fig. 154, taken from the interesting memoir of Guillet which I have cited several times,[1] places these facts well in evidence.

[1] *Le Génie Civil*, 1911, II, p. 286.

The various surfaces of fracture reproduced in the figure, some of which are distinctly fibrous while the others are "grained," are, in fact, obtained by breaking in different ways at different points, quite near to each other, the same bar of cemented soft steel.

The examination of the "fiber" of the surfaces of fracture may have some practical value when always carried out under identical conditions, by the same workman who has taken care to find out, on the basis of preliminary tests, what structure ought to be observed for each form of specimen and for each kind of steel to obtain good results.

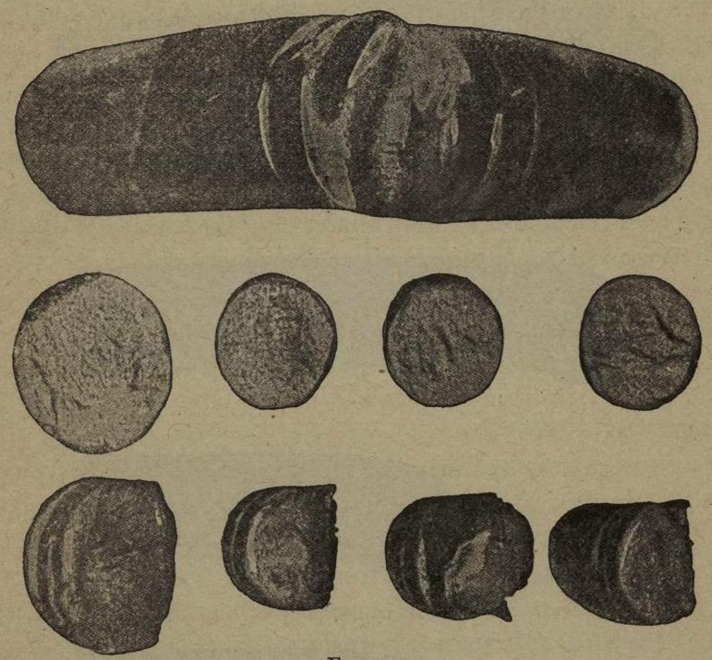

Fig. 154.

Another criterion quite frequently followed in practice to judge of the greater or lesser brittleness of the "core" of a cemented specimen, consists in observing the maximum angle through which the specimen can be bent before breaking, under the action of one or more shocks or of a force applied gradually.

But the results which can be attained with this method are also very far from having any absolute value, for the following reason: As is well known, the cemented and hardened zone, being composed of a steel incapable of undergoing appreciable elongation under tensile forces, quickly splits at the first deformations undergone by the specimen subjected to the bending test. These cracks, which show especially (as appears clearly in Fig. 154) in the convex part of the bent specimen, by propagating themselves, even slightly, into the mass of the soft metal constituting the core of the cemented steel produce there the special effects of a series of very sharp cuts. And it is well known how such cuts lower enormously the resistance to bending and to shock of the metallic piece in which they are made, giving rise to a kind of phenomenon of "inoculation" of the surfaces of fracture which are produced there as the result of the mechanical force.

For this reason, the method of applying the force to produce fracture by bending cemented specimens influences the behavior of these specimens to an enormously greater extent than in the case of homogeneous specimens.

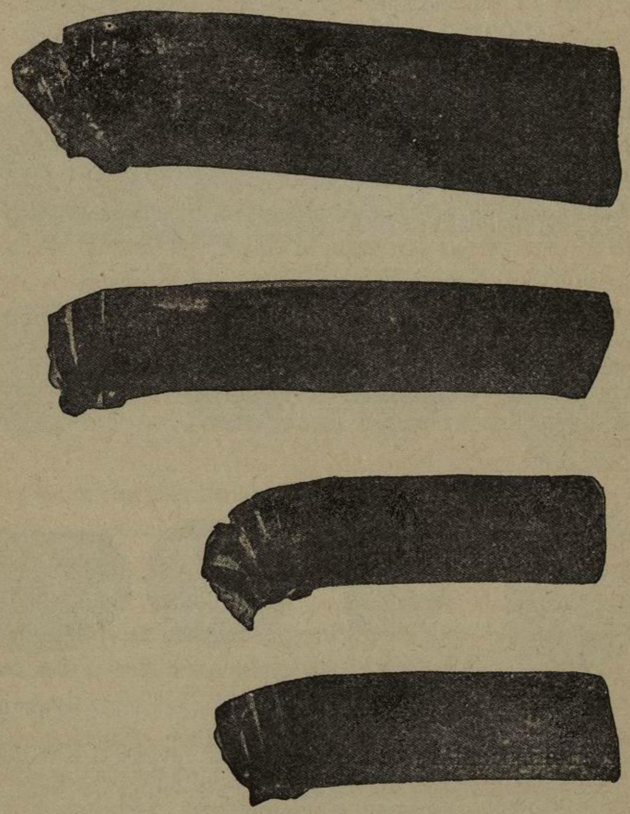

Fig. 155.

An example of the different behavior of a cemented and quenched specimen under the action of shocks applied under various conditions is furnished by Fig. 155, also taken from the same memoir of Guillet just cited. The two fractures shown in the figure were made at two points of a same cemented bar, not more than 10 cm. distant from each other. The first (between the two pieces shown at the bottom of the figure) was obtained by a series of weak shocks and was produced only after the specimen had undergone marked deformation. The second (between the two pieces shown in the top part of the figure) was, on the contrary, obtained with strong and sudden shocks; it

is clearly to be seen that the fracture was produced without any previous marked deformation of the specimen.

The only manner of determining with certainty and of expressing in numbers the brittleness of the core of a cemented piece is the shock test, carried out under the well-known "normal" conditions; that is, by breaking a bar of well-defined form with a single blow of a mass moving with a definite *vis viva*, and measuring the residual *vis viva* of the striking mass after the breaking of the specimen. The determinations just referred to can be carried out with various apparatus, such as the Charpy pendulum, the Fremont hammer and the Guillery fly-wheel apparatus.

In the case of the cemented steels *it is absolutely necessary* that the normal bar which is to be subjected to the shock test *should be taken entirely from the core of the cemented specimen* and should contain no part of the carburized zone. This is for two essential reasons:

First of all, in the well-known special form of the normal test piece now generally adopted,[1] the part of it in which the fracture must begin as the result of the shock of the striking mass of the test apparatus is precisely that which, owing to its form (hole of 4 mm. in diameter and 30 mm. in depth), is always cemented under conditions very different from those average ones under which the objects have been cemented whose mechanical properties are to be judged.

In the second place, the presence in the test pieces to be subjected to the shock test of a highly carburized and hardened external zone gives rise to the phenomena of "inoculation" of the surfaces of fracture already referred to and reduces, therefore, the apparent tenacity of the metal constituting the core of the cemented piece to an extent always large but which is most variable, and which depends, more than on the nature of the metal used, on a great number of small causes which it is most difficult, if not impossible, to take into account in practice.

When cemented objects are manufactured whose mechanical properties it is desired to make absolutely sure, the test of the brittleness of the metal constituting the core of the cemented and hardened pieces must be repeated every time that a steel of a new make is used or that it is desired to introduce modifications of some importance in the heat treatment of the cemented pieces.

A second point which we have seen is of importance for the quality of a piece of cemented steel is the variation in the hardness of the steel constituting

[1] As is well known, this is the test piece proposed by Charpy. It is a prism 160 mm. long with square section of 30 mm. to the side, with a cylindrical hole 4 mm. in diameter, of which one of the generatrices coincides with one of the two minor axes of symmetry of the prism; the metal which remains on one side of the hole is cut with a saw in the shortest way, and therefore normally to one face. On the side of the cut the bar is supported by two knife edges placed at distance of 120 mm., while the blunt knife edge, connected to the striking mass, strikes the opposite face, corresponding to the axis of the hole.

the carburized zone, as we pass through successive layers of this zone. Characteristic variations in the hardness of a cemented and quenched piece may depend on the variations in the concentration of the carbon in the cemented zone as far as they are due to the manner of conducting the cementation and also on the manner in which the subsequent heat treatments of the cemented piece have been conducted. The examination of the merely cemented control test pieces can not alone suffice, therefore, to establish the cause of a definite "distribution of the hardness" in the cemented zones of objects subjected later to further heat treatment. Further heat treatments may not only make the "distribution of the hardness" vary on account of the fact that they exercise their action with different efficacy at different depths in the mass of the steel, but also because their application, carried out under definite conditions, may also cause the distribution of the carbon to vary, within quite wide limits, in the cemented zones. This is caused especially by the heat treatment favoring or hindering the processes of segregation occurring during the cooling of the masses of steel of non-uniform composition.

It follows that it is necessary to complete the examination of the characteristic properties of the successive layers of the cemented zones, carried out on simply cemented control test pieces, by a similar examination of the cemented and hardened zones.

In general, this examination also renders the piece on which it is carried out useless, so that, if we except the cases just referred to, this examination is made on test pieces cemented and hardened under conditions as similar as possible to the treatment of those which it is desired to control.

In any case, it is necessary, first of all, to make a plane section normal to the surface of the piece. This section, recognizing the hardness of the cemented and quenched metal, can be made only by means of a disk of abrasive material (for example, carborundum) revolving with a high velocity and constantly fed with an abundant stream of cold water. This last precaution is absolutely necessary to prevent the great heating from altering the effects of the original thermal treatment to which the cemented piece was subjected.

When deep cemented zones are dealt with (as, for example, those which are obtained in ordinary ship armor) it is easy to control directly on the plane section of the cemented zone the hardness of the steel of the various layers by using center punches of a steel of definite composition, hardened and tempered under well-defined and constant conditions. By always using punches identical with each other, even in form, and always delivering the blow of the hammer in the same way, the examination of the stamp left by the punch on the plane surface of the cemented steel and that of the deformations or the fractures suffered at the same time by the point of the punch permit of obtaining sufficiently approximate indications as to the mechanical properties of the steels tested. These indications, however, have an exclusively relative value and depend to the greatest degree on the personal factor of the experimenter.

Considerably more precise results, possessing a certain absolute value and which can be expressed in figures, are obtained by substituting, under the same conditions as just indicated, for the test made with the punch the hardness tests carried out with the well-known apparatus of Brinell or of Shore. However, the first method—that of Brinell—can furnish precise results only for the layers of medium hardness, so that the data which can be obtained with it for the surface layers of the cemented zones can not be rigorously compared with those which it furnishes for the deeper layers. The data obtained by the Brinell method for the harder parts of the cemented and tempered zones (for example, above the hardness number 600) will, however, have real practical value if considered solely in their relations to each other. As to the results which are obtained with the Shore sclerometer, there are difficulties in practice in obtaining them under conditions such that they are rigorously comparable with each other.

It is clear that no one of the three sclerometric methods just referred to is applicable in practice when the thickness of the cemented zone is less than 4 or 5 mm. This is true in the large majority of the cases in practice, but interesting indications as to the "distribution of the hardness" in the cemented and hardened zones can then be obtained by using the Martens diamond point sclerometer.

Finally, useful indications can often be secured, especially as to the *causes* of a given distribution of hardness, by means of the microscopic examination of sections made across the cemented and hardened zone. And it is further evident that this means of investigation is the only one which permits of distinguishing if a definite variation in the hardness is due to a variation in the concentration of the carbon or to a difference in the conditions of hardening. I cannot enter here into details as to the method of interpreting the results of the micrographic examination of the cemented and hardened pieces, but it is clear that this interpretation does not require any special knowledge other than ordinarily used in the microscopic examination of any other kind of hardened steel. The appearance of the martensite and the degree of its transformation into its successive segregation products, from osmondite to lamellar pearlite, permit of judging with certainty of the effects produced by the hardening and by the recovery in each of the individual layers of the cemented zone and of thus separating the variations in the hardness due to these effects from those due to variations in the concentration of the carbon. The disappearance of the constituents characteristic of γ-iron steels, a disappearance which (as is well known) rarely manifests itself in practice for carbon steels but easily occurs for a large number of special steels of low transformation temperature, permits of distinguishing easily if the phenomena of deficient hardness or of excessive brittleness which manifest themselves throughout *a whole layer* of the cemented zone are due to ill-chosen conditions of quenching or to a local deficiency or excess in carburization due to irregularities in the cementation.

The microscopic examination of the sections of the cemented test pieces, extended to the metal constituting the "core," can furnish very interesting information as to the most suitable conditions for the "regeneration quenching" of this metal.

A detailed study of such observations would present no peculiarity because these observations were applied to cemented steels rather than to homogeneous steels, so that, while it might logically find a place in a general treatise on the processes of hardening, it would be out of place in discussing merely the control of the cemented products, and a study of those of their properties which depend, directly or indirectly, on the cementation.

Among the methods for the testing of the cemented and hardened pieces which can be used without ruining the piece to which they are applied, the determination of the surface hardness of the cemented and quenched pieces is of most practical importance. In the very great majority of cases, the property which it must be sought to obtain, to the maximum degree compatible with a not too excessive brittleness, is "mineralogical hardness" upon the surface of the cemented and hardened pieces. It is well known that this property, which can also be designated as "resistance to abrasion," is measured by the greater or lesser difficulty with which a sharp body, of a hardness markedly higher than that of the surface examined, can scratch this surface.

The method most frequently adopted in works to control the surface hardness of the cemented and quenched pieces consists in trying to attack them with a file with a fine edge. It is easy to understand how such a test is not precise, the results obtained by it depending first of all on the hardness and on the state of the edge of the file, and then on the way of making the test and on the personal equation of the workman in estimating the greater or lesser "bite" of the file on the metal tested. Moreover, the impossibility of representing the results of the test in figures is evident.

Notwithstanding this, the file test is still widely used in practice as being the simplest, and owing to the fact that it does not require the use of complicated apparatus or of precise methods of measurement, it can be entrusted to a workman. To carry out this test, it is desirable to use files of a very fine edge and of as constant a quality as possible. Given the maximum carbon contents and the conditions of quenching which we have seen are to be preferred for the cemented steels, it would be well to use files made of a steel with 0.9–1.0% of carbon, hardened between 780° and 800° C. and tempered toward 200° C.

Data considerably more precise and which can be expressed in figures are obtained with the Martens sclerometer. In works practice, the use of this apparatus presents some disadvantages, first of all because the apparatus is delicate and must be operated with a certain care, and then because the sclerometer, in the form in which it is ordinarily constructed, is not suited for determining the surface hardness of pieces of large dimensions and of complicated form.

This last disadvantage can be eliminated by modifying the apparatus in such a way as to leave a large free space below the diamond point and supplying it with a universal support which will make it easy to fix even large pieces of a complicated form in such a way that the section of their surface at which it is desired to determine the hardness will be about horizontal. It is desirable that this modification should be completed by making the piece to be examined stationary and, on the other hand, making the diamond point move with its load.

It is well known that even when the steel examined is homogeneous throughout its whole mass, the results of the hardness tests made "by abrasion," by one of the methods indicated above, are in no wise connected by simple relations with the results furnished by the other methods of measurement based on the penetration, *without abrasion*, of a hard body into the mass of the steel.

In the case, then, in which the tests above referred to are made on pieces only superficially cemented, so that the action of the hard body penetrating into the steel, transmitted to the soft layers lying beneath the carburized zone, can not be considered as null, the results furnished by the two methods of testing differ from each other to a still more marked degree, because the differences which are present in the case of the homogeneous steels are increased by those due to the mechanical properties of the metal constituting the core of the cemented piece. The cemented layer communicates to this a part of the force exercised by the hard body penetrating into it, a part which is greater the thinner and harder this layer.

It is clear, therefore, that the results of the methods of testing belonging to the second group, especially if considered in connection with those furnished by the methods belonging to the first, must be capable of furnishing, if suitably interpreted, indications as to the depth of the cementation. From this point of view they present marked practical interest.

Among the methods of the second group, there is largely used in practice, to supplement the file test, the penetration test with a punch of definite hardness and form, struck with a hammer.[1] As to the degree of exactness of this method, the observations already made in connection with the file test can be repeated, for it is clear that the results will depend on the hardness of the punch used, on the form of its point, on the force of the

[1] In the hardness tests with the punch, the workman is strongly advised to protect his eyes, by means of goggles, from the very dangerous splinters of steel which are detached either from the punch or from the piece tested.

blow of the hammer and on the manner of estimating the resistance offered by the metal.

Here too, then, it is a question of results which can not be expressed in figures, and which depend to a large extent on the estimation of the workman.

As an approximation, it may be said that in using a punch of ordinary tool steel, hardened at about 750° C. and tempered at about 200° and striking it with medium force, if the surface hardness has been found good by the file test, the fact that the cemented zone is completely perforated by the punch is a proof that the thickness of this zone does not exceed two or three tenths of a millimeter.

Under the same conditions, well-hardened cemented zones of a thickness greater than 0.3 mm. blunt the point of the punch.

The impossibility of giving more precise general rules on these methods of testing is evident. It is certain, however, that by making a series of preliminary tests on cemented zones of a thickness first approximately tested by examination of the surfaces of fracture, and by always working then under identical conditions, using identical files and punches treated in the same way, it is possible to acquire sufficient practice to get quite precise data as to the depth of cemented zones up to a thickness of even 1 to 1.2 mm. For thicker zones there would be needed too large punches, struck with too great a force, to make it possible to practically carry out the test on cemented and hardened pieces of moderate dimensions.

In these last cases, and even for the thinner zones, when it is desired to obtain more precise results, an analogous test may be made under considerably better conditions by comparing the results furnished by the Martens sclerometer (or some other analogous one, such, for example, as that of Turner or that of Jaggar) with those furnished by hardness tests based on the measurement of the resistance to penetration of a sphere (Brinell method) or of a cone (Ludwik method) of quenched hard steel. In this case also, the results furnished by the first method of testing (resistance to abrasion) are independent of the depth of the cemented zone, while the results of the methods of testing of the second group are closely related to this last quantity. Knowing what resistance to penetration corresponds to a definite resistance to abrasion when the steel tested is uniform throughout its whole mass, or is cemented to a considerable depth (7–8 mm.), the difference between the resistance to penetration thus deduced and that directly determined on a cemented and hardened piece can furnish a measure of the depth of the cemented zone of this piece. It is clear that this difference increases, other than with decrease in the thickness of the cemented zone, also with increase in the pressure under which the resistance to penetration is determined. So that, in the case with which we are now dealing, comparable data can be had only on the basis of "hardness numbers" (Brinell or Ludwik) obtained by

measurements made under a constant, well-defined pressure. This condition is not necessary, within certain quite wide limits, for the simple determination of the hardness number of a homogeneous steel.

The fact that there is not known (and probably does not exist) a simple relation between the numbers which represent, for a same homogeneous material, the resistance to abrasion determined with the Martens sclerometer and the resistance to penetration determined with the methods of Brinell or of Ludwik, and that such a relation is not known between the numbers which represent the results furnished by the two classes of methods of testing and the thickness of the cemented zone on which these tests were made, causes the method for the determination of the thickness of the cemented and hardened zone to furnish precise and sure data only by making a large number of preliminary tests on materials analogous to those which are to be tested.

It will be necessary, therefore, to prepare a certain number of test pieces (in the form of parallelepipedons) of the same steel as the pieces that are to be tested, and to cement them to different, exactly controlled, depths. This control can be made by examination of the surface of fracture of the cemented and hardened test piece, but it is preferable to make it on the test piece (heated) by means of the microscopic examination of a section normal to the cemented surface, polished and etched with alcoholic solution of picric acid. In this way can also be estimated the maximum concentration reached by the carbon in the cemented zones, so as to take it into account in the subsequent application of the data obtained.

For every depth of cementation are prepared series of various test pieces, each being quenched under different, well-defined conditions as nearly as possible the same as the various conditions under which the pieces that are to be controlled are to be quenched.

Abrasion tests are then made on the individual test pieces by the Martens sclerometer, and penetration tests by the Brinell or Ludwik methods, the results of each of these being noted and collected in tables. Then, making the same tests on the cemented and hardened pieces which are to be controlled, we look in the tables compiled in the way indicated above for the "abrasion" number nearest to that obtained, for which the corresponding number of hardness to penetration is also nearest to that obtained for the piece which is controlled. The depth of the cemented zone of the test piece to which these two hardness numbers correspond will be the nearest to that of the piece subjected to control.

This method, which in the description appears complicated, is of rapid and easy application when conducted systematically and when series of numerous pieces made of uniform materials and treated in a similar way are to be controlled, since in this case it suffices to prepare a limited number of comparison test pieces.

The indications furnished by this method are precise enough for all practical purposes.

The methods of testing the hardness based on determination of the resistance to the slow penetration of a hard body also furnish, indirectly, interesting indications as to the degree of brittleness of the metal constituting the cemented and hardened zone.

Especially interesting, from this point of view, are the indications which can be obtained by examining the appearance, the dimensions and the arrangement of the cracks which are always produced in the imprint left by the steel sphere used for the Brinell test when this test is made under a quite high pressure. The minimum pressure necessary in order that the observations just referred to may give good results is the higher the deeper the cemented zone. In the cases which ordinarily present themselves in the practice of cementation of mechanical pieces, it is often necessary to reach pressures of 20 to 30 tons; this requires the use of apparatus more powerful than those which are usually employed for the Brinell test (maximum pressure, 5000 kg.).

The brittleness of the cemented zone, determined on the basis just referred to, can evidently not be expressed in figures, and an estimate of real practical importance as to its value can be given only after long experience.

The various methods for the determination of the surface hardness, especially the methods based on resistance to abrasion, enable one to recognize extremely thin cemented zones, and so to control with certainty the efficacy of the means of "protection" applied to the parts of the cemented pieces where it is desired to preserve the original tenacity and plasticity of the metal.

For these purposes the simple file test gives results of sufficient precision and certainty. In some cases, in which special guarantees are required, recourse is had to the Martens sclerometer, or to that of Jaggar, for the testing of the zones protected from cementation.

Where such test has revealed insufficient surface hardness of the cemented and hardened piece, it is still necessary to learn the cause of this fact, in order, if possible, to remedy it in the pieces examined, or to correct the further treatment.

The principal causes of insufficient surface hardness in a cemented and quenched piece may be the following: 1. Insufficient thickness of the cemented zone; 2. insufficient concentration of the carbon in the cemented zone; 3. superficial decarburization of the cemented piece, produced in the course of the heat treatments which have followed the cementation; 4. not sufficiently rapid quenching or excessive tempering.

Let us examine separately the distinctive characters of each of these four cases:

1. We have already seen how the excessive thinness of the cemented zone reveals itself by the characteristics of insufficient hardness only with the tests made by the "penetration" methods (Brinell or Ludwik), while it does not appear in any way in the "abrasion" tests (Martens, Jaggar, etc.). In fact, the relations between the results of the tests made by the two different methods permit, to a certain degree, of measuring the thickness of the cemented zone.

2. A too low concentration of the carbon in the entire cemented zone is revealed when both the abrasion and the penetration tests give too low hardness values. Too slow quenching or excessive tempering also produce similar effects, but microscopic examination permits of distinguishing the two cases from each other.

3. Superficial decarburization occurs quite frequently, as is well known, in the course of the ordinary processes of hardening, tempering and annealing. It is also well known, however, that, omitting the exceptional cases, in which the heat treatments are carried out without any precaution or those in which the pieces treated are of very large dimensions (armor plates), the decarburized zones, though often having their carbon content reduced to 0.20% and sometimes down to 0.05%, are in general very thin. In ordinary mechanical pieces, hardened and tempered with care, it is rare that the thickness of the decarburized zone exceeds one- or two-tenths of a millimeter. In such usual cases, and whenever the cemented zone is so thick that the decarburization affects less than half of its original thickness,[1] the abrasion test (file, Martens sclerometer, etc.) will give excessively low values as compared with the "penetration" tests (punch, Brinell test, etc.). And, in fact, the relation between the hardness numbers obtained by the two groups of tests will furnish useful indications as to the extent of the decarburization.

Useful indications for the "diagnosis" of superficial decarburization of the cemented and hardened pieces can also be obtained from the comparison of the hardness numbers obtained by the Brinell apparatus and by the Shore scleroscope (resiliometer), respectively.

In fact, while the presence in the hardened pieces of a decarburized zone 0.1 to 0.8 mm. thick does not produce a very marked diminution in the hardness number determined by the Brinell method, the hardness numbers determined by the Shore method on the same pieces come out excessively low.

To show within what limits this phenomenon manifests itself, we give in the following table some experimental data taken from a memoir of Portevin and Berjot.[2] The experiments were made by heating three samples of steel with 1.4% of carbon in an oxidizing atmosphere so as to decarburize

[1] It is clear that when this happens, all the hardness tests will give low values, and the cementation must be considered as having entirely failed.

[2] A. Portevin and H. Berjot, *Expériences sur la dureté des aciers trempés, etc.* (*Revue de Métallurgie; Mémoires*, 1910, p. 63).

them superficially in a manner perfectly uniform for each piece, but to a depth varying from one piece to the other. In each piece there were measured the depth of the decarburization, under the microscope, and the hardness after quenching at 740° C. The results were the following:

No.	Carbon content at surface	Thickness of hypo-eutectic layer in mm.	Thickness of eutectic layer in mm.	Height of rebound after hardening	Diameter of Brinell imprint (10 mm. sphere) (3000 kg. pressure
1	0.85	0.0	0.18	80	2.39
2	0.4	0.48	1.00	41	2.94
3	0.2	0.84	1.50	32	2.89

As is seen, for the extreme values the superficial decarburization has produced a decrease of 17% in the original value of the hardness number determined by the Brinell method, while the corresponding decrease in the hardness number determined by the Shore method reaches 60% of the original value.

The differences between the hardness numbers obtained by the two methods may also be utilized for the measurement of the depth of the *decarburized* zone along lines entirely analogous to those indicated for the measurement of the depth of the *cemented* zones. Here too, as in that case, it will be necessary to make a series of hardness determinations by the two methods on the pieces cemented and superficially decarburized under conditions exactly controlled with the microscope, and, with the data thus obtained, compile comparative tables which are then referred to for the control tests of the cemented and hardened pieces.[1]

Experience shows that this method can furnish very useful results in practice.

4. I have already pointed out how insufficient quenching or excessive tempering have the effect of lowering both the hardness numbers determined by abrasion (Martens) and those determined by penetration (Brinell). When this occurs, only microscopic examination can determine to which of the two causes this is due. It is well known, in fact, that the presence and the state of the martensite (and, really, of γ-iron) and the extent of its transformation into osmondite and into the further products, down to

[1]The same comparison of the Brinell and Shore hardness numbers must furnish useful indications as to the depth of the cemented zones. This results from the interesting experiments reported by Portevin and Berjot in the Memoir cited. (See especially the data reported on p. 69 of that Memoir.) Not yet having had occasion, however, to make sufficiently extensive series of technical tests on this method, we can not say whether it gives in practice better or worse results than those which are obtained by the method, which we have already extensively tried in practice and which is described in the preceding pages, founded on the comparison between the hardness numbers determined by the Martens sclerometer and those determined by the Brinell method.

sorbite and to pearlite, furnish precise and sure indications as to the "degree" of the hardening and tempering.

It is known, also, that in this case, as in every other case in which metallic alloys in the state of metastable equilibrium are to be examined, it is necessary to use the greatest care in carrying out the grinding and the final polishing of the metallic surface so as to prevent the mechanical action of these operations raising even slightly the temperature of the metal. The surest means of achieving this consists in keeping the metallic surface under an abundant stream of water during all these operations. It is also well to frequently interrupt the grinding and the polishing.

Besides the tests to which I have just referred, the microscopic examination of the surface of the cemented and hardened pieces can also reveal one of the most frequent causes of the brittleness of the cemented and hardened zones. In fact, in speaking of the hardening of the hyper-eutectic cemented zones (such as are the majority of those obtained by the usual processes of cementation), I have pointed out how special precautions are necessary so that the heat treatment may not produce a total disappearance of the laminæ of cementite. It is moreover well known that the presence of these are the cause of great brittleness, the effects of which make themselves felt even in the "core" of the cemented pieces, owing to the phenomenon of the "inoculation" of the surfaces of fracture as the result of the sharp cracks which are produced corresponding to the laminæ of cementite. Now, the microscopic examination very easily reveals the presence of the undissolved cementite.

There remains, then, the control of the *form* of the simply cemented pieces and of those cemented and hardened. This control has great practical importance, in view of the fact that there are quite numerous causes which tend, during cementation and quenching, to produce deformation of the metallic pieces.

We have also seen that this control must be carried out with great care, both on the pieces which have undergone only the first quenching, so as to effect a first approximate rectification, and on those which have undergone the final hardening and tempering, so as to effect final straightening.

It is clear, however, that the methods and the operations for controlling the deformations of the cemented and hardened pieces differ in no way from those usually employed for ordinary mechanical operations on surface plates, gauges, calipers, etc.

It is not possible to establish rules of a general character for the depth of cementation best suited for the cemented zone for a given use. This must be determined on the basis of the known properties which steel assumes as the result of a given carburization and estimated by one who has studied this object in all its practical details. Such a study is made by the mechanical constructor rather than by the technologist dealing with the cementation. The latter must simply place himself in the position of obtaining, with the greatest possible approximation, cemented zones possessing the characteristics required by the mechanical constructor, who alone can know with precision the nature of the service to which the cemented and hardened pieces are to be subjected.

Summarizing, we may say that the methods of control spoken of permit of determining the following principal defects which may present themselves in the cemented and hardened pieces, and, in the majority of cases, of recognizing their causes:

1. Excess or deficiency in carburization.
2. Insufficient protection of the regions which are not to be cemented.
3. Sudden variations in the concentration of the carbon in the successive layers of the cemented zone.
4. Lack of uniformity in the cemented zone.
5. Deformations of the pieces after the cementation and after the hardening.
6. Inequalities in the temperature.
7. Excess or deficiency of hardening.
8. Cracks in the cemented and hardened zone.
9. Brittleness of the cemented and hardened zone (tendency to exfoliation, etc.)
10. Brittleness of the "core" of the cemented pieces.

The causes of these troubles and the means of remedying them are in part extremely easy to perceive; thus, for example, it is hardly necessary to say that when a cemented piece is too soft owing to deficiency of hardening it is necessary to quench it more energetically. In other cases, the observations and tests fully discussed in the first and second parts of this volume are sufficient to reveal their causes and their remedies. To cite two examples, the causes and the remedies of an excess or a deficiency in the concentration of the carbon in the cemented zones are explained by the phenomena of chemical equilibrium during the processes of cementation; and those of an irregularity in the intensity of the cementation in the various parts of a piece, due to irregularities in the heating, are clearly explained by the effects of temperature on the velocity of the cementation.

CHAPTER V

SOME PATENTS CONCERNING PROCESSES FOR THE CEMENTATION OF IRON AND STEEL

In the preceding chapters we have cited several times rules and data contained in some patents. But desiring to limit ourselves to the study of cementation proper, we have cited only patents concerning processes on which quite precise and sure data were known. In fact, with a few exceptions we have limited ourselves to reporting quantitative data whose exactness was based on our own experimental investigations, or because they had been directly observed by us in practice.

But this is possible for only a limited number of the processes of cementation patented in various countries. In the majority of cases, in fact, the descriptions accompanying the claims constituting the essential part of the patents are written with every care to avoid disclosing the best way of usefully carrying out the claims in practice. From the point of view of the inventor it would appear sufficient that a description should contain the correct directions, but mixed with any amount of useless data; so that in case of a legal contest it can be maintained that the correct directions were really given.

We will, however, refer briefly to some patents whose true practical value is unknown to us, either for the reasons just referred to or because, although the descriptions furnished are clear and simple, we have not been able personally to test their results nor to obtain information from any one who has tested them. We will limit this review to reporting from many such a few examples adapted to show some of the directions in which inventors have entered this field.

Many inventors have attempted to increase the activity of the carburizing mixtures by the addition of the most varied substances, in the choice of which it is sometimes difficult to find the guiding principle or any reasoning based on well ascertained facts.

One of the substances whose addition to the cementation powders is most frequently proposed is borax. Thus, Th. Langer proposes (German patent, No. 55544, Kl. 18, 1891) the following mixture:

Common salt	15 parts
Yellow prussiate of potassium	5 parts
Borax	1 part

or the other: