DEPARTMENT OF COMMERCE

CIRCULAR

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 42

METALLOGRAPHIC TESTING

[1st Edition]
Issued September 1, 1913

WASHINGTON
GOVERNMENT PRINTING OFFICE
1913

DEPARTMENT OF COMMERCE

CIRCULAR

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 42

METALLOGRAPHIC TESTING

[1st Edition]
Issued September 1, 1913

WASHINGTON
GOVERNMENT PRINTING OFFICE
1913

METALLOGRAPHIC TESTING

CONTENTS

INTRODUCTORY

1. PURPOSE OF CIRCULAR

It is not intended to make this circular a treatise on the scientific and technical importance and development of metallography as a method of testing. Primarily, its purpose is to bring before those interested the tests of this nature which the Bureau of Standards is equipped for carrying out and the conditions under which such tests are made.

2. TECHNICAL IMPORTANCE OF THE METHOD

The physical properties of an alloy are much more closely related to the minute structure than they are to the ultimate chemical composition. To-day no one questions the value of the chemical laboratory in metallurgical work, but the microscopical examination when properly interpreted may be of greater value than the chemical in explaining the properties and predicting the uses of an alloy. By way of illustration, a medium carbon steel may have properties ranging at the one end from a very hard metal of practically no ductility and almost impossible to machine to one fairly soft, ductile, and machined with no difficulty at the other extreme. The ultimate composition remains constant throughout and tells us nothing. For the proper explanation we must know either the complete treatment the steel has received or turn to the microscopic examination and infer such treatment by the proper interpretation of the results obtained. Like all new methods too much has been predicted of it and the nonrealization of these extravagant expectations has had much to do with the disfavor with which the method is sometimes received by a few.

I. SCOPE OF THE SCIENCE OF METALLOGRAPHY

1. RECENT GROWTH

The past few years have witnessed a remarkable growth in the progress of metallography. It is one of the youngest of the sciences. From a relatively unimportant branch of physical chemistry it has developed into a method of investigation of the properties of metals and alloys on a par with chemical and physical testing, and it is often of service in explaining difficulties which are inexplicable by other methods. It is finding its place to-day in all works' laboratories which deal primarily with the manufacture and working of metals.

2. REAL SCOPE OF SUBJECT

As a science, metallography may be considered from two viewpoints. In a narrow sense it is limited to the study of the microscopic structure of metals, the mode of crystallization, the constituents and their determinations, etc. More broadly considered, however, it includes all those methods of investigation which throw some light on the internal make-up of the metals. In fact, it is just what the name signifies, "the science of metals." It is in this latter sense that we shall consider it. The results of physical and mechanical testing, as well as of chemical and thermal analysis, thus

find a place in the complete "metallographic" analysis of an alloy and are essential for a complete understanding of its properties.

3. METHODS OF ATTACK

Chief among the methods of metallographic study are thermal analysis, microscopic analysis, and the correlation of the various physical properties with the internal structure. The result of all this investigation for any one series of alloys is conveniently expressed in the so-called "equilibrium diagram"—the temperature-concentration curve—and any single alloy is best studied by referring it to its place in this diagram. For any particular sample, the thermal and microscopic analyses together with the determination of the mechanical properties and chemical analysis are quite sufficient to determine the qualities of the alloy in question for ordinary uses. For special purposes other properties must be known, such as specific heat, specific resistance, thermal expansion, thermoelectric behavior, magnetic properties, etc., and the change of such properties with the change of temperature.

II. THERMAL ANALYSIS

Definite information as to the fusion point of any metal, together with the changes in structure and properties with change of temperature, is of utmost importance for the proper working of that metal. Thermal analysis by the "cooling-curve" method and consequent location of the transformation or critical points or regions gives information as to the temperature at which the structure, and hence, also, the properties of the metal, change. The whole field of annealing and hardening of steels, for example, depends upon the phenomenon of transformation points. Not all alloys show them, but given the cooling or heating curve for any particular one that does, we can, from the location and number of the critical points, in a general way, tell much as to the different properties of that alloy and the necessary preliminary treatment for securing desired results.

1. THE COOLING-CURVE METHOD

When allowed to cool from a relatively high temperature, many substances, among them many of the alloys, do not cool at the uniformly retarded rate to be expected, but show one or more retardations in the rate of cooling. Such phenomena are caused by the spontaneous evolution of heat within the cooling body. On the other hand, upon heating an absorption of heat may be recorded. There are three well-known causes for such

heat evolutions and absorptions—(1) a change of physical state, as liquid to solid, etc.; (2) the formation of a chemical compound which is very often accompanied by its "heat of formation" and conversely the dissociation of a compound by an absorption of heat; (3) a transformation from one form of substance with definite properties to another with entirely new properties, i. e., an allotropic or a polymorphic change. In general, these three are sufficient to explain the cause of any heat change, though in a few cases it becomes necessary to make a modification or an entirely new assumption. The proper interpretation of the results of thermal analysis has proved the value of the method in explaining the structural transformations in alloys which result from changes in temperature and which could be detected in almost no other way.

The method of obtaining cooling curves is very simple in theory and consists merely of the recording of temperature in terms of time or some quantity varying both with time and temperature. In practice it may become very complex, depending upon the precision and accuracy of the results desired. Because of the tendency toward undercooling, the cooling curve does not always give the true conditions and the heating curve is preferred by some for very precise work. Also in commercial practice the heating curve is often to be preferred, as it gives the temperature above which a sample must be heated for a given heat treatment. In general, it is advantageous to have both the heating and cooling curves.

2. METHODS OF RECORDING COOLING CURVES[1]

The simplest and oldest method of plotting cooling curves is to plot temperatures directly against time (θ vs t). A body having no critical points will by this method give a smooth cruve, the deviation from a straight line being mainly due to the change of specific heat of the body at different temperatures and to the changes in the rate of cooling. In case there is an evolution of heat upon cooling it will be indicated as a sudden break in the curve which may become horizontal if the phenomenon is confined to a single temperature, or even a rise if the evolution of heat more than compensates for the heat loss by radiation, etc.

A second method is to plot successive equal changes of temperature against the actual intervals of time required for the corresponding temperature changes, the inverse rate curve $\left(\theta \text{ vs } \frac{dt}{d\theta}\right)$. In this case the transformations appear as sharp "peaks," while a body showing no such changes gives

[1] See G. K. Burgess, On Methods of Obtaining Cooling Curves, Bull. Bureau of Standards, Reprint 99.

a graph which approaches a vertical line for uniform cooling. Of the two methods, the inverse rate curve is preferred in that it may be made to show very clearly heat evolutions that are quite inconspicuous on the time-temperature curve.

A second class of cooling curves involves the use of another heated body that shows no critical transformations and the measurement of the difference of temperature between this second body and the one under examination by means of some form of differential thermocouple. Equal changes of temperature of the body under investigation are plotted against the difference in temperature between the body and the "neutral" (θ vs $\theta-\theta'$). A modification of this differential curve is the "derived differential." This calls for a replotting of values obtained from the previous curve. The values of $\frac{d(\theta-\theta')}{d\theta}$, i. e., the temperature difference per degree change of temperature is plotted against temperature, $\left(\theta \text{ vs } \frac{d(\theta-\theta')}{d\theta}\right)$.

Other forms have been used, but these four are the common ones. The time-temperature and inverse rate curves disregard any irregularities in the heating or cooling of the furnace or any change from outside sources, such as drafts, which necessarily will be recorded in the resulting curve. In using these methods the furnace must be supplied with some device for heating it uniformly, and in case this is not to be had the neutral body is made use of. Of the two differential methods the derived differential is the one preferred in expressing results, as it takes account of and aims to eliminate any differences in the rate of cooling or heating of the two bodies due to differences in heat capacities, radiation, etc.

3. EQUIPMENT

In the laboratory it is preferable in most cases to take heating and cooling curves in vacuo and in an electric resistance furnace, heated by an automatically controlled source of steady current, preferably alternating current furnished by a motor-generator driven by a storage battery. At this Bureau the apparatus is arranged for taking simultaneously, on the same sample, inverse rate and differential curves in this way. Temperatures and differences are taken at 2° intervals with 0.4 mm Pt, 90 Pt-10 Rh thermocouples by means of a potentiometer of the dial type and sensitive galvanometer. Times intervals are recorded to 0.1 second on a cylindrical chronograph.

III. MICROSCOPIC ANALYSIS

1. METHOD

The microscopic analysis presupposes that the chemical composition is known, at least approximately. In principle it is simple, and for opaque substances such as alloys consists of the examination of carefully polished and etched specimens by means of a microscope using vertical illumination. The polishing must be carefully done, using various grades of very fine polishing powders, depending upon the mechanical nature of the alloy in question. Almost invariably the surface will require etching with some suitable reagent to differentiate the various constituents. The general study of the microscopic structure in any case will vary considerably with the different alloys and with the aim of the investigation. The purpose may be the determination of the definite constituents making up the alloy, thus supplementing a chemical analysis, or attention may be directed to the purity and soundness of the metal and the occurrence and amount of foreign substances, thus supplementing and explaining the results of mechanical testing. Again, in alloys whose structure and properties depend largely upon the treatment—both thermal and mechanical—that the piece has received, the purpose of the examination may be to make certain that the metal has received the proper treatment for the use for which it is intended.

2. EQUILIBRIUM DIAGRAM

A single alloy can not well be studied as an isolated example but must be referred to its proper place in its series. In fact the thorough study of the series from the viewpoint of the "Phase rule," as set forth in the equilibrium diagram, is the proper foundation for a complete understanding of the properties and structure of any single alloy of that series. The conditions represented by the equilibrium curve are ideal and seldom if ever completely realized, but are so instructive as to what is to be expected in the way of structure and properties under varying conditions of temperature and composition that its importance can not be overestimated.

3. APPLICATIONS TO IRON AND STEEL

It is in the field of iron and steel that the technical application of the microscopic method has been most fully worked out, and it may be of interest to mention here a few of the applications.

(*a*) **Correlation of Thermal Treatment with Internal Structure**—(1) *"Burning" of Steel.*—Steel which has been heated to a too high temperature becomes brittle and worthless. The commonly accepted explanation is that

the metal has been carried to the point of incipient fusion and that this fusion is the cause of the trouble rather than the oxidation which may perhaps accompany it. The microscopic examination is the surest and quickest way of detecting such a condition. As yet, no sure way of remedying such a condition, short of remelting, is known.

(2) *Annealing Temperatures.*—For certain purposes, such as ease in machining, the refining of the structure of steel castings, etc., steel should be annealed. The maximum softness and finest structure are, in general, conferred upon any grade of steel by heating it just through its critical range, holding it long enough so that all is of a uniform temperature and then suitably cooling it. As soon as this critical range is passed the grain size begins to increase, and approximately this increase of size may be said to be directly proportional to the elevation of the temperature above the critical. A similar condition results from holding the steel for a longer time at a lower temperature which is still above the critical. This increase in grain size is accompanied by brittleness and loss of strength. Though the annealing temperatures are best determined by the use of some form of pyrometer, the microscopic examination is an excellent check, as every change that results from improper heating is recorded in the structure. The proper annealing temperature varies considerably with the composition; no definite rule can be formulated, though up to the eutectoid ratio (0.85 per cent C) the temperature is lower the higher the percentage of carbon. The presence of other elements, as in the alloy steels, modifies the practice considerably. A knowledge of the microscopic structure is also essential in fixing upon the heat treatment required for the improvement of the properties of any given sample of steel.

(3) *Tempering.*—When steel is heated to a temperature which is above the transformation range, the carbon of the steel is in the form of a solid solution; by cooling suddenly from this temperature this condition may be in part retained. While the cause of hardness of steel may still be considered an open question, it undoubtedly bears some relation to this solid solution of carbon.

The case of a medium carbon steel will illustrate. After sudden cooling by suitable quenching, such a steel is in a state of unstable equilibrium, very hard, and often too brittle for use. By heating or "tempering," the internal strains are released, and the steel passes back gradually to its normal condition. By proper regulation of the temperature of reheating any desired degree of hardness may be retained. This temperature may be checked by microscopic examination of test pieces, as a definite change of internal structure accompanies the change of temperature.

In practice, small pieces are hardened and tempered in the same process. The part which is to be tempered is cooled suddenly and then allowed to warm up to the required degree by the heat still stored up in the hotter portion. The color of the oxide film which accompanies this reheating is used as a measure of the temperature, and hence also of the degree of hardness. More improved methods require the use of various baths held at carefully regulated temperatures. The microscopic examination will form an excellent check as to the degree to which the structure has been changed.

(*b*) **Homogeneity of Product**—(1) *Examination "in situ."*—A preliminary macroscopic examination is often of value in suggesting points for further study using higher magnification. For ordinary macroscopical examination a section is planed off and polished somewhat. This is then etched with some suitable reagent as tincture of iodine, etc., depending upon the structure to be studied. In this way very coarse crystalline structure, large inclusions of foreign matter, segregations of various constituents, etc., are made evident at the start. In fact, some investigators claim that practically all the microscopic work should be done upon the larger piece in the foundry, etc., even to the taking of photomicrographs. While this is of great value in cases where the piece in question can not be mutilated for specimens, in general the method is too rough except for low magnifications.

The chemical constituents of common steel that show the greatest tendency to segregate—i. e., to collect in certain portions of the casting—are carbon, phosphorus, and sulphur. The amount of impurities in the segregated parts may be so great as to destroy the useful properties of the whole. In this connection may be mentioned the use of the photographic bromide paper in obtaining "sulphur prints," which thus show directly the areas of segregation. By a slight modification, by substituting a plastic clay coated with bromide gelatine, fractures may be studied for segregation areas in the same way.

(2) *Impurities, Grain Size, etc.*—The properties of steel are profoundly modified by the presence of seemingly insignificant amounts of foreign matter. Often these are a product of the process of manufacture and unless segregated may have but little bad influence. There are some impurities, however, which should never be present—e. g., iron oxide. The presence of this is an indication of faulty manufacture, and the whole product should be properly condemned. While certain "impurities" are necessarily to be expected as a result of the manufacturing process, the microscope will show whether they occur in a form which may prove dangerous, and will also

show up those impurities whose presence indicates poor control of the manufacturing process.

The size of the grain is closely related to the mechanical properties, and has already been referred to. The distribution of the microscopic constituents aside from grain size is of importance. This is especially true in case of constituents with pronounced properties, such as brittleness, hardness, etc. In general, for the best mechanical properties the microscopic constituents should be disseminated throughout the mass as uniformly as possible.

(3) *Definitions.*—Various metallurgical products are sometimes sold under misleading terms—e. g., wrought iron, cast steel, etc. The correct definitions of all iron and steel materials have not, as yet, been definitely settled upon, but provisionally, at least, the Bureau will use the official definitions submitted at the Fifth and Sixth Congresses of the International Society for Testing Materials. While the detection of such substitutions is largely a matter of wide experience, the microscopic examination is a very useful aid in this work. In many cases it is the quickest and surest one to apply.

(*c*) **Mechanical Treatment.**—The treatment the product receives during its manufacture—i. e., if rolled or forged—bears a close relation to its properties. Mechanical work if properly carried on will improve the strength of the steel several fold. The temperature at which such work should be finished bears a definite relation to the critical range of the steel used. It will vary considerably with different steels, according to the different carbon contents, and in no case should it be carried on much below the lower critical point. Such cold working leaves its impress in the distorted grain structure and in the modification of mechanical properties. The action of rolling and forging upon the grain size is a refining one and if discontinued, much above the beginning of the critical range, the steel will be left in the undesirable coarse-grained condition. In practice the mechanical treatment should be and usually is closely correlated with the thermal treatment, and the microscopic examination is a good check upon this correlation.

(*d*) **Special Metallurgical Processes.**—(1) *Case Hardening.*—The microscopic examination finds an important application in the control of some special metallurgical processes. When iron or low carbon steel is heated above the critical range in the presence of carbon it gradually absorbs it, the depth of the carburized layer being a function of the time of heating. A practical application of this principle is the case hardening of steel articles which require a very hard resistant surface and a comparatively soft body beneath. The quickest and surest way of determining the progress of this

process is by microscopic examination of sections perpendicular to the surface, when the depth of the case may be easily and accurately measured. The same principle is made use of in the manufacture of steel by the cementation process.

(2) "*Malleable Cast Iron.*"—The reverse of the above process, i. e., the removal of carbon from highly carburized metal by heating above the critical range in the presence of an oxidizing substance, or by simple heat alone, is made use of in the manufacture of malleable cast iron. In its original condition the cast iron used for the manufacture of malleable castings contains most of its carbon in the form of cementite, the definite chemical compound Fe_3C. If such iron is heated at a temperature above the pearlite point with or without an oxidizing packing, this compound dissociates with the formation of graphite which is in the form of very fine particles. This forms the well-known "black-heart" castings, while the more complete removal of the carbon by the use of an oxidizing packing mixture and a higher temperature gives the "white-heart" castings. Microscopic examination is the only way of quickly determining the extent to which the process has been carried.

(3) *Other Processes.*—The microscopic method is also used to advantage in the investigation of welding by various processes, as electric, thermite, etc. Any change due to carburization, etc., as a result of such processes as oxy-acetylene cutting of steel may also be investigated advantageously. In fact, the method is an ideal one to use wherever the change in the composition of the metal is a local or a gradual one.

(*e*) **Examination After Failure.**—One of the principal and most valuable applications of metallography is the recognition of faulty structure and hence the cause of failure. Often metals fail during service and no cause can readily be assigned for the breakdown. Microscopic examination in such cases will often determine whether there are any flaws in the structure such as could account for the failure in question. The strength of any material is fundamentally a function of its ultimate physical structure, hence the more we know of the minute structure of steels or other metals whose strength and other mechanical properties are unquestioned the better able are we to judge of the cause of failure in other cases. It is really an application of all of our knowledge of the structure and behavior of metals and one is not to be limited to the use of the microscope alone.

Too much, however, should not be expected of such an examination. The purpose is not to displace or supersede any of the other well-known methods of testing, but to coordinate with them. Microscopic examination, properly interpreted and in conjunction with mechanical testing and chemical

analysis, is capable of proving itself a very useful aid in suggesting remedies for the prevention of similar cases of failure.

The above list of applications of microscopic analysis in the field of ferrous alloys is not complete in any sense. There are so many special points that arise, depending upon the piece under examination, that anything like a complete list is impossible. Enough has been given to show a few of the more important industrial applications in this field.

4. APPLICATIONS TO THE NONFERROUS ALLOYS

Many of the nonferrous alloys have been studied from the viewpoint of the "Phase rule," and the equilibrium diagram established for a large number of them, but the industrial application of these principles to these alloys has not been developed to the same extent as for iron and steel. The few applications that are made vary so, depending upon the alloy in question and its use, that no convenient classification can as yet be made. The further extension of this method of investigation of the properties of metals and alloys in the nonferrous field is much to be desired.

5. MAGNIFICATIONS

No arbitrary standard of magnification can well be adopted that will apply equally well in all cases. This will vary necessarily with the optical apparatus at hand and also with the alloy under examination. This Bureau will, however, provisionally use the following series in the preparation of photomicrographs, depending upon the nature of the request: 10, 25, 50, 100, 250, 500, and 1000 diameters. In special cases magnification greater than 1000 diameters may be arranged for.

6. SAMPLING AND TEST SPECIMENS

Definite directions can not be given for the taking of samples for metallographic examination, as the sampling will vary with the purpose of the examination. In some cases the defective spots will be the ones chosen, while if the sample is to be representative of the whole, such must be carefully avoided. In choosing samples which are to be representative of the whole mass it is best to choose several at some distance apart, choosing a spot each time that appears to be typical of the structure of that part. In the taking of samples of materials which must fulfill certain specifications the Bureau should be consulted with reference to the method of sampling to be used. In the case of specially heat-treated alloys, e. g., hardened steels, it is better to chip a sample out from the main mass than to attempt to apply the same treatment to a small piece of the metal. In all cases of examination for cause of failure the Bureau should be corresponded with before the shipment is made.

IV. CHEMICAL AND MECHANICAL TESTING

For a thorough understanding of an alloy and its properties, the chemical, thermal, mechanical, and microscopic examinations should all be made and correlated. For special purposes other properties may need to be determined. Mechanical and physical tests may be arranged for by correspondence. In general, chemical analysis will be made for individuals only in cases of dispute or when some question of considerable scientific or technical importance is involved.

V. REPORTS AND CERTIFICATES

Photomicrographs issued will be accompanied by statements as to the various constituents which are shown and the conditions under which the test was made.

In describing the microscopic structure of iron and steel the Bureau will conform to the "Nomenclature of the Microscopic Substances and Structures of Iron and Steel," recommended by the Sixth Congress of the International Society for Testing Materials.

In general, the Bureau will not in a formal report express an opinion as to the properties and suitability of an alloy for any particular purpose. In reporting upon causes of failure the probable cause as revealed by the study of the piece in question will be pointed out when possible.

VI. REGULATIONS REGARDING TESTS

1. LIST OF TESTS OF METALS AND ALLOYS

The Bureau is equipped at present for the following metallographic tests:

1. Determination of the fusing or freezing point (or range) of any alloy or metal.

2. Determination of the heating and cooling curves for the location of critical or transformation points or ranges.

3. Heat treatment of any alloy, as specified, such as annealing, hardening, tempering to any desired degree, etc.

4. Microscopic examination of any alloy or metal, together with the photomicrograph of the same of desired magnification. In case no magnification is specified, that one will be used that best shows the effect sought.

5. Microscopic examination of sample alloy after receiving any specified heat treatment with photomicrograph of same of desired magnification.

6. Examination of metals which have failed in service, for evidence of flaws in their internal structure. Such examinations will include a macroscopic investigation, consisting of polishing, etching, and study of large

sections, together with "sulphur prints," etc., for the purpose of locating suspicious areas, segregations, seams, etc. A detailed microscopic study of the suspected spots is then made. When advisable, mechanical tests will also be made, and in special cases chemical analysis.

7. Special tests not included in the above may be arranged for by correspondence. Such tests may include determination of specific heats, temperature coefficient of electrical resistance and of thermal expansion, thermoelectric properties, etc.

2. DIRECTIONS

(*a*) **Application.**—The request for examination of any material or for any test should state explicitly the purposes for which such examination is to be made. The heat treatment desired should be clearly specified, and the chemical composition of the sample (approximately, at least) should be stated. Wherever possible the required fee should accompany the application.

(*b*) **Marks of Identification.**—Both the samples and the packages in which they are shipped should be plainly marked to facilitate identification. Preferably the name of the shipper should be on the outside of each package, and a list of the contents should be inclosed in each package, each sample being given a special number or mark. This special number or mark should be stamped upon the proper sample, and in the written requests for tests, samples should be referred to by the proper number.

(*c*) **Size of Sample.**—The size and shape of the sample for microscopic examination will depend much upon the nature of the alloy. Metals which can be sawed should be cut so as to present a polishing surface of not less than 0.5 cm by 0.5 cm, preferably 1 by 1 cm, or larger. Hard brittle alloys which can not be cut to shape may be submitted in almost any form.

For cooling and heating curves the samples should preferably be in cylinders, 25 mm (1 inch) in length by 15 mm (5/8 inch) diameter. Samples for microscopic examination after special heat treatment should approximate the same in size.

For the determination of melting points, the size of the sample will depend entirely upon the nature of the material. For alloys of the common cheaper elements, a volume of about 500 cc is desired, but for the rare and more costly elements, samples of any size may be submitted, even to microscopic amounts.

(*d*) **Shipping Directions.**—Samples should be securely packed in cases, which may be used for returning them in case this is desired. In general, such samples will not be returned; in case of microscopic examination only, part of the sample, polished ready for examination, will be sent when

requested with the results of the test. In every case the Bureau retains a part of the sample submitted.

(*e*) **Address.**—Packages should be addressed "Bureau of Standards, Washington, D. C." When delivered in person or by messenger, articles should be left at the office of the Bureau, together with a written request for the test desired.

(*f*) **Remittances.**—Fees may be remitted by money order or check drawn to the order of the "Bureau of Standards." No articles are returned or results of tests submitted until all fees due thereon are received. Delays will be avoided by remitting fees, with the request for test.

FEE SCHEDULE 223—Metallography

3. FEES [2]

(*a*) Determination of the fusion point of metal or alloy	$10.00
(*b*) Cooling curve of a steel or other alloy for critical points	25.00
(*c*) Annealing or other heat treatment of small specimens	2.50
(*d*) Determination of temperature coefficient of electrical resistance at high temperature	20.00
(*e*) Microscopic examination (preparation of specimen with photomicrograph of same):	
(1) Magnification up to 500 diameters for first print	5.00
(2) Magnification 500 to 1000 diameters for first print	7.50
(3) Magnification above 1000 diameters, fee depends upon magnification, but minimum charge for first print	10.00
(4) For each succeeding print in every case	.50
(5) Microscopic examination without photomicrograph, half of above charges.	

In the case of soft alloys or those whose sections for examination are very difficult to prepare, the above charges may be increased.

(*a*) **Examination After Failure.**—Fee will depend upon the nature and amount of work required.

Minimum fee	$25.00

4. DISCOUNTS

When three or more test specimens of the same kind or class requiring the same test on each are submitted together a discount of 25 per cent from the fees in this schedule will be allowed.

For educational and scientific institutions and societies a discount of 50 per cent will be allowed on all tests.

S. W. Stratton,
Director.

Approved:
E. F. Sweet,
Acting Secretary.

[2] See "Discounts" on this page.