25 CENTS

TESTING HARDNESS AND DURABILITY OF METALS

SECOND EDITION

MACHINERY'S REFERENCE BOOK NO. 62
PUBLISHED BY MACHINERY, NEW YORK

MACHINERY'S REFERENCE SERIES

EACH NUMBER IS ONE UNIT IN A COMPLETE LIBRARY OF
MACHINE DESIGN AND SHOP PRACTICE REVISED AND
REPUBLISHED FROM MACHINERY

NUMBER 62

TESTING THE HARDNESS AND DURABILITY OF METALS

CONTENTS

140-148 Lafayette Street, New York City

INTRODUCTION*

Even when men first began to harden steel, they probably sought some method of ascertaining in particular cases whether their object had been accomplished. Perhaps the testing tool was nothing more than a fragment of flint or another piece of steel known to be hard. Certain jewels--as the diamond—are well suited to a process which depends upon scratching. In fact, this process is in common use everywhere even at the present day. The test by filing is not to be despised as it is easily applied, and if the file is a good one, the results are sufficiently accurate and reliable for a considerable class of work. But the file is an instrument inadequate to the requirements of modern metallurgists and manufacturers. This is true for two reasons: First, the alloy steels seem to possess the property of being able to resist a file, apart from hardness. Thus, a piece of manganese self-hardening tool steel may be, in reality, softer than a specimen of a pure carbon steel, and yet resist the attacks of the file equally well. In explanation of this phenomenon, it has been suggested that the hard manganese resists the file while the iron substratum remains soft. The combination as a whole would not be so hard, although able to withstand the file. This, however, seems really to involve the proposition that such steel is not a perfect chemical combination, but that particles of manganese are held imbedded in iron or an iron alloy. Perhaps this may be so, but if it is true, then the action of such steel on the file is very similar to that of an emery wheel. The emery itself is very hard, but is held in a matrix that is soft. However, whether we accept this explanation or not, it is doubtful whether we have good reason to contend that a specimen of alloy steel is as hard as a piece of pure carbon steel, merely because it resists the file equally well.

The second objection to the file is that it affords no reliable means of making accurate comparisons between different degrees of hardness. It is sometimes of importance in cases where one element of a machine slides against another to ascertain which of the two is the harder. The difference may be very slight, yet it will readily be granted that this difference might become of importance if lubrication failed, for the harder piece would then cut or wear the softer. If such a contingency is possible, then it is important that the more expensive part shall be the harder. A little reflection will convince one that this principle of associating a harder valuable part with a softer less valuable part, has application everywhere in machine construction; but in order to apply this principle widely, it is necessary to be able to determine differences in hardness where these differences are quite small in amount.

---

* J. F. Springer, MACHINERY, October, 1908.

CHAPTER I

METHODS OF TESTING THE HARDNESS OF METALS*

Few properties of iron and steel are of more importance than that of hardness. In some cases, as with a cutting tool or a pressure die, the metal is practically valueless unless it can retain a sharp edge; while in other instances, where the material has to be machined or cut or trued to shape, even a relatively slight increase of hardness is the cause of much inconvenience and expense. In a third class of material a good wearing surface is of prime importance; while, lastly, hardness may often serve as an indication of a degree of brittleness and untrustworthiness which might perhaps be otherwise unsuspected.

Hardness may be defined as the property of resisting penetration, and, conversely, a hard body is one which, under suitable conditions, readily penetrates a softer material. There are, however, in metals various kinds or manifestations of hardness according to the form of stress to which the metal may be subjected. These include tensile hardness, cutting hardness, abrasion hardness, and elastic hardness; doubtless other varieties could also be recognized when the experimental conditions are modified so as to bring into operation properties of the material in addition to that of simple, or what may be conveniently called mineralogical hardness. This has been defined by Dana as "the resistance offered by a smooth surface to abrasion." The usual quantitative tests for hardness are static in character, but the conditions are profoundly modified when the penetrating body is moving with greater or less velocity. The resistance to the action of running water, to the effect of a sand-blast, or to the result of the pounding of a heavy locomotive on a steel rail, affords examples of what might perhaps for purposes of distinction be called dynamic hardness, which is a branch of the subject which has received little examination.

Comparison will be made in the following of four typical methods of measuring hardness. Those selected include the sclerometer, introduced by the author in 1886; the scleroscope, recently invented by Shore; the form of indentation test adopted by Brinell about 1900; and the drill test introduced by Keep a few years earlier. Each of these methods has been used in actual works practice, and by various persons other than the inventor, and may thus be regarded as being typical of the particular class of test to which it belongs. Among the many other forms of test the microsclerometer and wearing tests call for special mention, though to these only incidental reference can be made.

---

* MACHINERY, August, 1909. Abstract of a paper read before the Iron and Steel Institute (Great Britain), May 14, 1909, by Prof. Thomas Turner, of the University of Birmingham.

The principles underlying the four methods selected for comparison may be briefly described as follows:

Turner's Sclerometer

In this form of test a weighted diamond point is drawn, once forward and once backward, over the smooth surface of the material to be tested. The hardness number is the weight in grammes required to produce a standard scratch. The scratch selected is one which is just visible to the naked eye as a dark line on a bright reflecting surface. It is also the scratch which can just be felt with the edge of a quill when the latter is drawn over the smooth surface at right angles to a series of such scratches produced by regularly increasing weights.

Shore's Scleroscope

In this instrument, described in detail in Chapter IV, a small cylinder of steel, with a hardened point, is allowed to fall upon the smooth surface of the metal to be tested, and the height of the rebound of the hammer is taken as the measure of hardness. The hammer weighs about 40 grains, the height of the rebound of hardened steel is in the neighborhood of 100 on the scale, or about 6¼ inches, while the total fall is about 10 inches or 255 millimeters.

Brinell's Test

In this method, described in detail in Chapter II, a hardened steel ball is pressed into the smooth surface of the metal so as to make an indentation of a size such as can be conveniently measured under the microscope. The spherical area of the indentation being calculated, and the pressure being known, the stress per unit of area when the ball comes to rest is calculated, and the hardness number obtained. Within certain limits the value obtained is independent of the size of the ball, and of the amount of pressure. In the original tests the steel ball was 10 millimeters (0.394 inch) in diameter, and the pressure was equal to a weight of 3000 kilogrammes; but a more convenient form of apparatus is now supplied by Mr. Brinell for works tests, while Mr. Stead and Mr. Derihon have introduced small portable instruments.

Keep's Test

In this form of apparatus a standard steel drill is caused to make a definite number of revolutions while it is pressed with standard force against the specimen to be tested. The hardness is automatically recorded on a diagram on which a dead soft material gives a horizontal line, while a material as hard as the drill itself gives a vertical line, intermediate hardness being represented by the corresponding angle between 0 and 90 degrees.

Comparison between Testing Methods

Each form of test has its advantages and its limitations. The sclerometer is cheap, portable, and easily applied, but it is not applicable to materials which do not possess a fairly smooth reflecting surface, and the standard scratch is only definitely recognized after some experience. The Shore test is simple, rapid, and definite for materials for which it is suited, and appears likely to have an important future; but further information is yet needed as to the exact property which is measured by this form of test. As shown by De Fréminville, the result obtained varies somewhat with the size and thickness of the sample, while if the test-piece is supported on a soft material, such as a plasticine, the results are valueless. It should also be pointed out that india-rubber gives a rebound of 23, which is equal to that of mild steel, while light soft pine wood gives a rebound of 40, which is nearly twice as great as that of gray cast iron. Curiously enough, hard wood, like teak, gives a rebound of about 12, while some samples are considerably lower than this. As illustrating the influence of the support, a sample of exceptionally hard rolled copper, about 0.040 inch in thickness, when supported on a block of hard steel, and tested with the blunt or "magnified" hammer supplied, gave a value of 30, which was increased to 34 when the copper was supported on wood. A sample of brass only gave a value of 17, and yet this brass would scratch the copper, while the copper would not scratch the brass. From these results it would seem that the Shore test is only applicable to a certain class of substances. It appears to test what may be termed the "elastic hardness," and gives high results with metals in the "worked hard" condition. Tests appear to show that good results are, however, obtained with glass and with porcelain, as well, of course, as with most metals.

The Brinell test is specially useful for constructive material; it is easily applied and definite, and is now of all hardness tests the one most employed. It appears to give satisfactory results with wood, but cannot be applied to very brittle materials, such as glass, or to hard minerals. Keep's test is specially suited for castings of all kinds, as it records not merely the surface hardness, but also that of the whole thickness, and gives indications of blowholes, hard streaks, and spongy places. Obviously, it can only be applied to materials the hardness of which is less than that of hardened steel.

Comparison of Results Obtained by Different Testing Methods

A very important question arises in connection with these various tests—namely, as to whether there is any observed agreement between the results which are arrived at by such entirely different methods. It will be noticed that in each case an arbitrary scale is adopted. If the weights used on the sclerometer had been ounces instead of grammes, the hardness numbers would naturally have been different. Similarly, Brinell's tests might have been expressed in tons and inches, or a different weight of hammer and height of scale adopted by Shore. Hence all that can be expected is a proportionality in the results, and if this is ascertained it should be possible to convert values on one scale into results on another.

An examination of results obtained by the four methods dealt with shows that, for relatively pure metals in their cast or normal condition, there is a general agreement which must be regarded as remarkable. In Table I will be found, in the first column, results which were published in the author's original paper on the hardness of metals in 1886. In the second column are the author's results with the Shore scleroscope, and these figures are in good agreement with those supplied by the maker of the instrument. In the third column are values taken from published results by Mr. Brinell and by Mr. Stead, but the numbers given have been divided by 6, as this figure has been found to suitably reduce the Brinell hardness values for purposes of comparison. It will be observed that either by accident or design the scale adopted for the scleroscope is, for practical purposes, identical with that of the sclerometer, while Mr. Brinell's values are proportional. The angles in Keep's tests could easily be made to show pretty close agreement with the other values. It would therefore appear that each instrument, with simple and homogeneous substances, must measure one and the same physical property, and gives results which are either in actual agreement with, or proportional to, the results obtained by the other forms of tests.

TABLE I. HARDNESS SCALES COMPARED

Metal	Sclerometer	Scleroscope	Brinell
Lead	1.0	1.0	1.0
Tin	2.5	3.0	2.5
Zinc	6.0	7.0	7.5
Copper, soft	8.0	8.0	....
Copper, hard	....	12.0	12.0
Softest iron	15.0	....	14.5
Mild steel	21.0	22.0	16–24
Soft cast iron	21–24	24.0	24.0
Rail steel	24.0	27.0	26–35
Hard cast iron	36.0	40.0	35.0
Hard white iron	72.0	70.0	75.0
Hardened steel	....	95.0	93.0

In practice, however, the use of relatively pure metals in the unworked or annealed condition is comparatively rare, unless we include in this category wrought iron and mild steel. Carbon steels and special steels consist largely of alloys, the complexity of which is profoundly modified by heat treatment; while copper, zinc, and their alloys are frequently hardened by rolling, drawing, or other mechanical treatment. The very important question therefore arises as to the extent to which the different methods of testing agree in their values for the hardening and tempering of steel, and for the hardness caused by mechanical treatment. From preliminary observations on the latter point the author is inclined to believe that metal which has been mechanically treated, as with hard-drawn rods or rolled sheets, has its tenacity increased out of proportion to its hardness as measured by a file or cutting tool. The sclerometer shows relatively little difference, for example, between hard-drawn and annealed copper, while the scleroscope shows an exaggerated effect, at all events in some cases. As the

Brinell test closely follows the tenacity, it too may be expected to show a marked difference between worked and annealed samples. The result in some cases is likely to be a confusion between elasticity or tenacity on the one hand, and true or mineralogical hardness on the other. For example, a piece of hard-rolled copper may give a greater hardness number than one of mild steel. Yet a tool made of mild steel will always cut copper, and no amount of cold-rolling will make copper cut steel. Hence great care is required when hardness values for different materials are compared.

Hardness of Steel in Hardened, Tempered or Annealed Condition

The question of agreement in reference to the true hardness of a sample of steel in the normal, hardened, tempered, or annealed condition is perhaps of even greater importance. To illustrate the kind of difficulty which arises, reference may be made to some recently published results by E. Maurer, in which samples of steel with varying content of carbon were heated to ascertained temperatures, quenched, and afterward tempered or annealed at given temperatures. The hardness of the samples was then determined. When the tempering heat was 300 degrees C., the loss of hardness in a sample containing 0.83 per cent of carbon was 11.1 per cent by the Shore method, and 38.0 per cent by the Brinell test. A steel with 0.95 per cent carbon tested in a similar manner by Heyn and Bauer with a Martens sclerometer gave a loss of hardness of 41.0 per cent; while lastly Boynton, with a Jagger sclerometer, using a steel with 0.86 per cent carbon, has recorded a loss of hardness on tempering at 300 degrees of only 9.0 per cent. The question may be put in this way: The steel is suited for making woodworking tools, if properly hardened and tempered. Is 300 degrees C. a proper tempering heat? According to the Shore test and the Jagger test the tool should be hard and cut well; but according to the Brinell test and the Martens sclerometer it has lost nearly half its original hardness, and should rapidly lose its cutting edge. Maurer states that everyday experience shows that with this class of tool steel a tempering heat of 300 degrees renders the metal useless for woodworking.

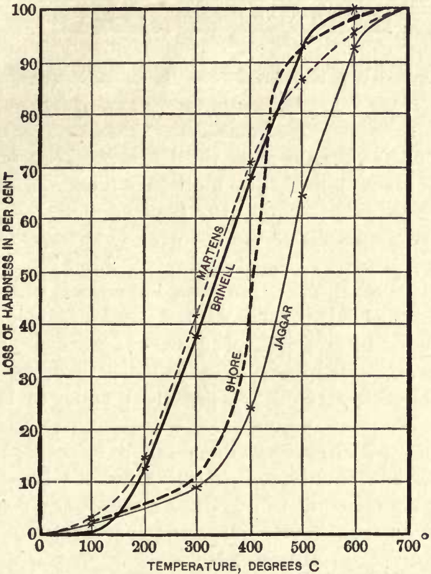
TABLE II. PERCENTAGE OF LOSS OF HARDNESS OF HARDENED STEEL WHEN TEMPERED TO VARIOUS TEMPERATURES, AS MEASURED BY DIFFERENT HARDNESS TESTING APPARATUS

Temperature of Heating, Degrees C.	Brinell Method (0.83 per cent Carbon)	Martens Sclerometer (0.95 per cent Carbon)	Jaggar Micro-sclerometer (0.86 per cent Carbon)	Shore's Method (0.83 per cent Carbon)
160	..	2.5	1.8	3.7
200	13	14.0	5.4	2.7
300	38	41.0	9.1	11.1
400	68	70.6	23.6	33.0*
500	94	87.5	64.0	92.5
600	100	95.7	94.5	100.0

* At 380 degrees C.

The results of the four sets of experiments are given in Table II.

The values are graphically represented in the engraving Fig. 1, from which it will be seen that the greatest difference occurs at about 300 degrees C., the loss of quenching hardness due to tempering being about four times as great when tested by the two first methods as compared with the results obtained when the steel is tested by the two latter methods given in the table.



Machinery,N.Y.

Fig. 1. Diagram showing Percentage of Loss of Hardness of Hardened Steel when Tempered to Various Temperatures, as Measured by Different Hardness Testing Apparatus

Martens and Heyn have recently pointed out that in the Brinell ball test for hardness, the indentations are frequently not circular, and are therefore difficult to measure, and that when testing hard materials the ball itself is appreciably flattened while under load. To diminish these sources of error Martens has introduced a special form of apparatus for measuring the depth of the indentation.

CHAPTER II

THE BRINELL METHOD OF TESTING THE HARDNESS OF METALS*

The method of testing the hardness of metals devised by Mr. J. A. Brinell has received very favorable attention from metallurgists in this, as well as in other countries. In 1900 Mr. Brinell, then chief engineer and technical manager of the Fagersta Iron and Steel Works in Sweden, first made public his method of testing the hardness of iron and steel, by submitting it to the Society of Swedish Engineers in Stockholm. At the meeting of the *Congrès International des Méthodes d'Essai des Matériaux de Construction* in Paris the same year the method attracted general attention, and its merits were duly acknowledged by awarding the inventor with a personal *Grand Prix* at the Paris Exposition. The method was first described in the English language by Mr. Axel Wahlberg in a paper before the Iron and Steel Institute in 1901. Since then, the practical value of this method has been amply substantiated on various occasions by means of comprehensive tests and investigations undertaken by several distinguished scientists in different countries. In working out his method, Brinell kept in view the necessity of taking into account the requirements that the method must be trustworthy, must be easy to learn and apply, and capable of being used on almost any piece of metal, and particularly, to be used on metal without in any way being destructive to the sample.

Principle of Brinell Method for Testing Hardness of Metals

The Brinell method, as mentioned in the previous chapter, consists in partly forcing a hardened steel ball into the sample to be tested so as to effect a slight spherical impression, the dimensions of which will then serve as a basis for ascertaining the hardness of the metal. The diameter of the impression is measured, and the spherical area of the concavity calculated. On dividing the amount of pressure required in kilogrammes for effecting the impression, by the area of the impression in square millimeters, an expression for the hardness of the material tested is obtained, this expression or number being called the *hardness numeral*. In order to render the results thus obtained by different tests directly comparable with one another, there has been adopted a common standard with regard to the size of ball as well as to the amount of loading. The standard diameter of the ball is 10 millimeters (0.3937 inch) and the pressure 3000 kilogrammes (6614 pounds) in the case of iron and steel, while in the case of softer metals a pressure of 500 kilogrammes (1102 pounds) is used. Any variation either in the size of the ball or the amount of loading will be apt to occasion more or less confusion without there being any advantage to compensate for such

---

* MACHINERY, September, 1908.

inconvenience. Besides, making any comparisons between results thus obtained in a different manner would be more or less troublesome, and complicated calculations would be required.

The diameter of the impression is measured by means of a microscope of suitable construction, and the hardness numeral may be obtained without calculation directly from the table given herewith, worked out for the standard diameter of ball and pressures mentioned. The formulas employed in the calculation of this table are as follows:

$$y = 2\pi r\,(r - \sqrt{r^2 - R^2}) \qquad (1)$$

$$H = \frac{K}{y} \qquad (2)$$

in which formulas

r = radius of ball in millimeters,
R = radius of depression in millimeters,
y = superficial area of depression in square millimeters,
K = pressure on ball in kilogrammes,
H = hardness numeral.

Suppose, for instance, that the radius of the ball equals 5 millimeters (0.1968 inch), and that the test is undertaken on a piece of steel, the pressure consequently applied being 3000 kilogrammes (6614 pounds). Assuming that we found the radius of the depression equal to 2 millimeters (0.07874 inch) by measurement, we have:

$$2\pi \times 5\,(5 - \sqrt{25 - 4}) = 13.13 = y,$$

and

$$\frac{3000}{13.13} = 228 = H,$$

which as we see agrees with the figure given in our table for a 4 millimeters diameter of impression.

Relation Between Hardness of Materials and Ultimate Strength

It has been pointed out by Mr. Brinell himself that this method of testing hardness of metals offers a most ready and convenient means of ascertaining within close limits the ultimate strength of iron and steel. This, in fact, is one of the most interesting and important results of this method of measuring hardness. In order to determine the ultimate strength of iron and steel, it is only necessary to establish a constant coefficient determined by experiments which serves as a factor by which the hardness numerals are multiplied, the product being the ultimate strength. Rather comprehensive experiments were undertaken with a considerable number of specimens of annealed material obtained from various steel works, for the purpose of establishing the coefficiency, by the present director of the Office for Testing Materials of the Royal Technical Institution at Stockholm. The results obtained were as follows:

For hardness numerals below 175, when the impression is effected transversely to the rolling direction, the coefficient equals 0.362; when the impression is effected in the rolling direction, the coefficient equals 0.354.

TABLE OF HARDNESS NUMERALS

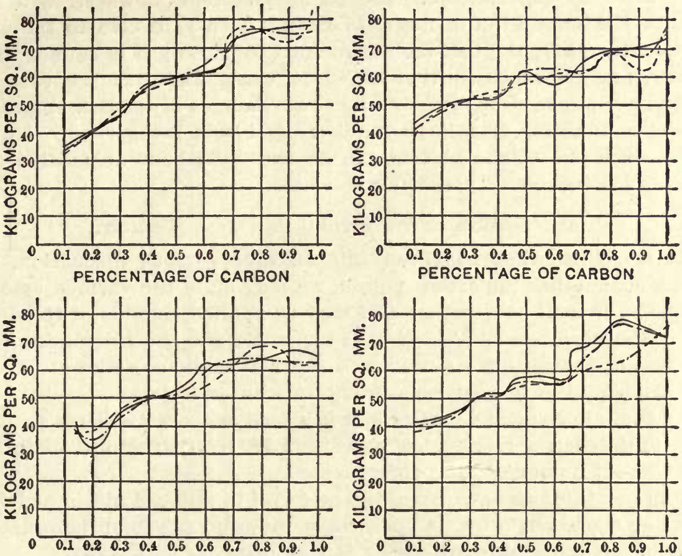
Steel ball of 10 millimeters diameter

Diameter of Impression, mm.	Hardness Numeral. Pressure, kg.		Diameter of Impression, mm.	Hardness Numeral. Pressure, kg.		Diameter of Impression, mm.	Hardness Numeral. Pressure, kg.		Diameter of Impression, mm.	Hardness Numeral. Pressure, kg.		Diameter of Impression, mm.	Hardness Numeral. Pressure, kg.	
	3000	500		3000	500		3000	500		3000	500		3000	500
2.00	946	158	3.00	418	70	4.00	228	38	5.00	143	23.8	6.00	95	15.9
2.05	898	150	3.05	402	67	4.05	223	37	5.05	140	23.3	6.05	94	15.6
2.10	857	143	3.10	387	65	4.10	217	36	5.10	137	22.8	6.10	92	15.3
2.15	817	136	3.15	375	63	4.15	212	35	5.15	134	22.3	6.15	90	15.1
2.20	782	130	3.20	364	61	4.20	207	34.5	5.20	131	21.8	6.20	89	14.8
2.25	744	124	3.25	351	59	4.25	202	33.6	5.25	128	21.5	6.25	87	14.5
2.30	713	119	3.30	340	57	4.30	196	32.6	5.30	126	21	6.30	86	14.3
2.35	683	114	3.35	332	55	4.35	192	32	5.35	124	20.6	6.35	84	14
2.40	652	109	3.40	321	54	4.40	187	31.2	5.40	121	20.1	6.40	82	13.8
2.45	627	105	3.45	311	52	4.45	183	30.4	5.45	118	19.7	6.45	81	13.5
2.50	600	100	3.50	302	50	4.50	179	29.7	5.50	116	19.3	6.50	80	13.3
2.55	578	96	3.55	293	49	4.55	174	29.1	5.55	114	19	6.55	79	13.1
2.60	555	93	3.60	286	48	4.60	170	28.4	5.60	112	18.6	6.60	77	12.8
2.65	532	89	3.65	277	46	4.65	166	27.8	5.65	109	18.2	6.65	76	12.6
2.70	512	86	3.70	269	45	4.70	163	27.2	5.70	107	17.8	6.70	74	12.4
2.75	495	83	3.75	262	44	4.75	159	26.5	5.75	105	17.5	6.75	73	12.2
2.80	477	80	3.80	255	43	4.80	156	25.9	5.80	103	17.2	6.80	71.5	11.9
2.85	460	77	3.85	248	41	4.85	153	25.4	5.85	101	16.9	6.85	70	11.7
2.90	444	74	3.90	241	40	4.90	149	24.9	5.90	99	16.6	6.90	69	11.5
2.95	430	73	3.95	235	39	4.95	146	24.4	5.95	97	16.2	6.95	68	11.3

For hardness numerals above 175, when the impression is effected transversely to the rolling direction, the coefficient equals 0.344; when the impression is effected in the rolling direction, the coefficient equals 0.324.

If the hardness numerals are multiplied by these coefficients, the result obtained will be the ultimate tensile strength of the material in kilogrammes per square millimeter. It is evident that coefficients can easily be worked out so that if the hardness numerals be multiplied by these the strength could be obtained in pounds per square inch.

Suppose, for instance, that a test of annealed steel by means of the Brinell ball test gave an impression of a diameter of 4.6 millimeters. Then the hardness numeral, according to our table, would be 170, and the ultimate tensile strength consequently 0.362 × 170 = 61.5 kilogrammes per square millimeter, provided the impression was effected transversely to the rolling direction.



Machinery,N.Y.

Fig. 2. Diagrams showing Relation between Results Obtained by Various Methods for Ascertaining the Ultimate Strength of Materials

In Fig. 2 are shown a number of diagrams which indicate the results obtained at the tests undertaken to ascertain the coefficients given. In these diagrams the full heavy line indicates the tensile strength of the material, as calculated from the ball tests in the rolling direction. The dotted lines indicate the strength as calculated from the ball tests in a transverse direction, and the "dash-dotted" lines show the actual tensile strength of the material as ascertained by ordinary methods for ascertaining this value. It is interesting to note how closely the three curves agree with one another, and considering the general uncertainty and variation met with when testing the same kind of material for tensile strength by the ordinary methods, it is safe to say that the ball test method comes nearly as close to the actual results as does any other method used. Especially within the range of the lower rates of carbon, or up to 0.5 per cent, or in other words, within the range of all ordinary construction materials, the coincidents are, in fact, so very nearly perfect as to be amply sufficient to satisfy all practical requirements.

In the case of any steel, whether it be annealed or not, that has been submitted to some further treatment of any other kind than annealing, such as cold working, etc., or in the case of any special steel, there would be other coefficients needed which would then also be ascertained by experiments. The same coefficient, however, will hold true for the same kind of material having been subjected to the same treatment. Thus, the ball testing method for strength is equally satisfactory, and far more convenient, in all cases where the rupture test would be applied. One of the greatest advantages of the Brinell method is that in the case of a large number of objects being required to be tested, each one of the objects can be tested without demolition, and without the trouble of preparing test bars.

Application of the Brinell Ball Test Method

Summarizing what has been said in the previous discussion, and adding some other important points, we may state the various uses for which the Brinell ball test method may be applied, outside of the direct test of the hardness of construction materials and the calculation from this test of the ultimate strength of the materials, as follows:

1. Determining the carbon content in iron and steel.
2. Examining various manufactured goods and objects, such as rails, tires, projectiles, armor plates, guns, gun barrels, structural materials, etc., without damage to the object tested.
3. Ascertaining the quality of the material in finished pieces and fragments of machinery even in such cases when no specimen bars are obtainable for undertaking ordinary tensile tests.
4. Ascertaining the effects of annealing and hardening of steel.
5. Ascertaining the homogeneity of hardening in any manufactured articles of hardened steel.
6. Ascertaining the hardening power of various quenching liquids and the influence of temperature of such liquids on the hardening results.
7. Ascertaining the effect of cold working on various materials.

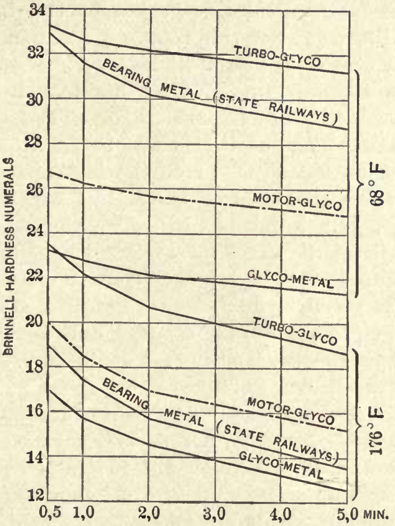
The Time Element in Hardness Tests by the Brinell System*

A diagram indicating the effect of the time element in hardness tests made by the Brinell method is shown in Fig. 3. The tests upon which this diagram is based were made by the German Glyco Metal Co. On the lower scale is given the time, in minutes, during which the pressure on the metal was permitted to act, while the scale on the left-hand side gives the hardness numerals according to the Brinell hard-

---

* MACHINERY, November, 1909.

ness scale. It will be noted that the longer the pressure was permitted to act, the greater was the impression made on the metal, so that a lower hardness numeral resulted. Two sets of curves are shown, one with the metal heated to 176 degrees F., and one with the metal at 68 degrees F. It is interesting to note that the curves in each set are almost parallel, except in one case, thus indicating that for *comparative* purposes the Brinell test is accurate no matter what the length of duration of pressure, provided, of course, that the various samples tested are all subjected to pressure for the same length of time. It is also interesting to note the difference in the hardness of the metal brought about by the change of temperature. It will be seen that at the higher temperature its hardness numeral is not only less than at the lower temperature, as, of course, would be expected, but when the pressure on the metal is permitted to remain for a longer time, the metal apparently gives away much easier to continuous pressure when heated than when at a lower temperature. Tests of this kind should be of great value in determining the relative value of bearing metals which for long periods are to be subjected to heavy pressures under increasing temperatures. A new factor in hardness testing is also introduced, which the Brinell method is particularly adapted to measure, *viz.*, the power of resistance of various metals to *continuous* pressure, a factor which may be found to vary considerably for different materials.



Machinery, N.Y.

Fig. 3. Curves showing the Variation in Results Obtained in Hardness Tests of Varying Duration

CHAPTER III

MACHINES FOR TESTING THE HARDNESS OF METALS BY THE BRINELL METHOD*

The method of applying the Brinell ball test was at first only possible in such establishments where a tensile testing machine was installed. As these machines are rather expensive, the use of the ball test method was limited. For this reason a Swedish firm, Aktiebolaget Alpha, Stockholm, Sweden, has designed and placed on the market a compact machine specially intended for making hardness tests. This machine, as shown in Fig. 4, consists of a hydraulic press acting downward, the lower part of the piston being fitted with a 10-millimeter steel ball *k* by means of which the impression is to be effected in the surface of the specimen or object to be tested. This object is placed on the support *s* which is vertically adjustable by means of the hand-wheel *r*, while at the same time it can be inclined sideways when this is needed on account of the irregular shape of the part tested. The whole apparatus is solidly mounted on a cast-iron stand. The pressure is effected by means of a small hand pump, and the amount of pressure can be read off directly in kilogrammes on the pressure gage mounted at the top of the machine.

In order to insure against any eventual non-working of the manometer, this machine is fitted with a special contrivance purporting to control in a most infallible manner the indications of that apparatus, while at the same time serving to prevent any excess of pressure beyond the exact amount needed according to the case. This controlling apparatus consists of a smaller cylinder, *a*, directly communicating with the press-cylinder. On being loaded with weights corresponding to the amount of pressure required, the piston in this cylinder will be pushed upward by the pressure effected within the press-cylinder at the very moment when the requisite testing pressure is attained. Owing to this additional device, there can thus be no question whatever of any mistake or any errors as to the testing results, that might eventually be due to the manometer getting out of order.

Method of Performing the Ball Test

The test specimen must be perfectly plane on the very spot where the impression is to be made. It is then placed on the support *s*, Fig. 4, which, as mentioned, is adjusted by means of the hand-wheel *r* so as to come into contact with the ball *k*. A few slow strokes of the hand pump will then cause the pressure needed to force the ball downward, and a slight impression will be obtained in the object tested, but as soon as the requisite amount of pressure has been attained, the upper piston is pushed with the controlling apparatus upward, as

---

* MACHINERY, September, 1908, and April, 1910.

previously described. On testing specimens of iron and steel, the pressure is maintained on the specimen for 15 seconds, but in the case of softer materials for at least half a minute. After the elapse of this time, the pressure is released, and the contact between the ball and the sample will cease. A spiral spring fitted within the cylinder, and being just of sufficient strength to overcome the weight of the press piston, pulls the same upward into its former position, while forcing the liquid back into its cistern. The diameter of the impression effected by the ball is then measured by the microscope *m*, which is specially constructed for this purpose, the results obtained by this measurement being exact within 0.05 millimeter (0.002 inch). Fig. 5 shows a cross-section through the cylinder and piston part of the machine. Another type of machine is designed for special tests in which

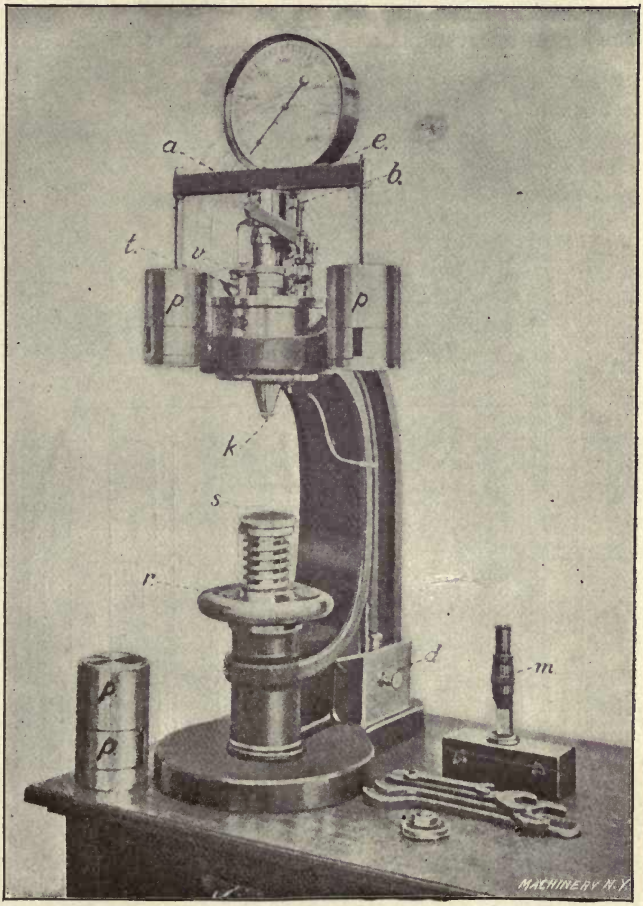


Fig. 4. Aktiebolaget Alpha's Machine for Testing Hardness of Metals

very high pressures are required. The ball in this machine is 19 millimeters (0.748 inch) in diameter, and the pressures employed vary from 3 to 50 tons. The construction and operation are otherwise exactly the same as that of the smaller machine in Fig. 4.

Derihon Portable Form of Brinell Hardness Testing Machine

The only disadvantage of the Brinell method for general practical use lies in the apparatus required and the comparative slowness of the operation. The apparatus just described, constructed in the form of a small hydraulic press, operated by hand, is rather heavy. It is evident that with such an apparatus, the work has to be brought to the machine, so that its regular use for inspection purposes in different parts of a manufacturing plant is impracticable.

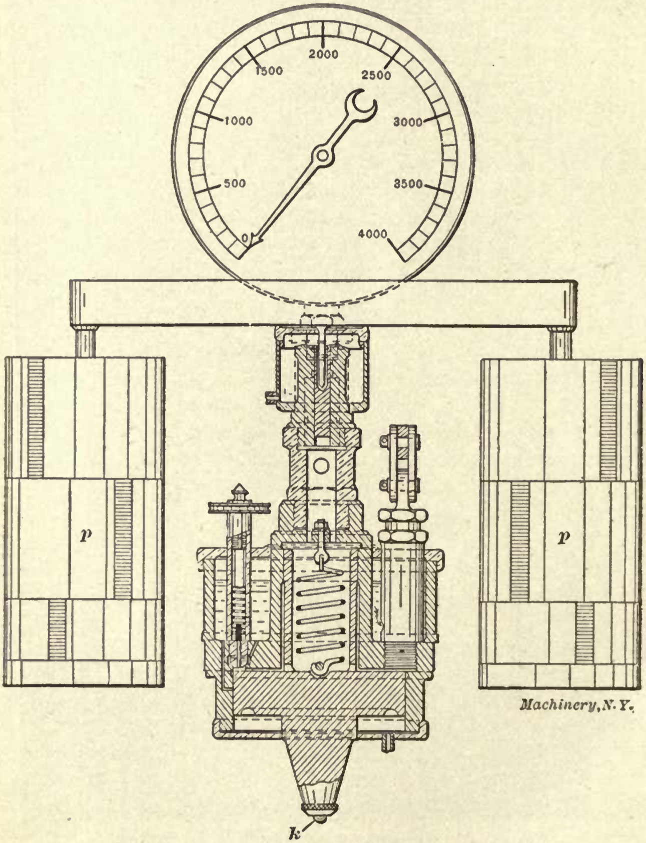


Fig. 5. Section of Press Cylinder of Machine in Fig. 4

The foregoing considerations lend interest to the apparatus shown in Figs. 6 and 7, which was devised by the Usines G. Derihon of Loucin, Belgium. This firm is an important manufacturer of high-grade drop forgings for automobile work, and it originally developed the machine for use in its own plant. As may be seen, the pressure is applied by a hand-operated screw, and the press is small enough to be perfectly portable, weighing only about 12 pounds.

The sectional view in Fig. 7 shows the action of the apparatus most clearly. The work is placed on the platen *F*, which rests in a spherical seat on top of adjusting screw *G*. By means of this self-adjusting seat, the work gets an even bearing and a direct pressure, even though its under surface may be quite out of true. The purpose of the adjusting screw *G* is, of course, to give a rapid adjustment for the thickness of the work. It will take in about 3 inches as shown. The thread of *G*, while of coarse pitch, still lies within the angle of repose, so that it is not disturbed when the pressure is applied by levers *M*.

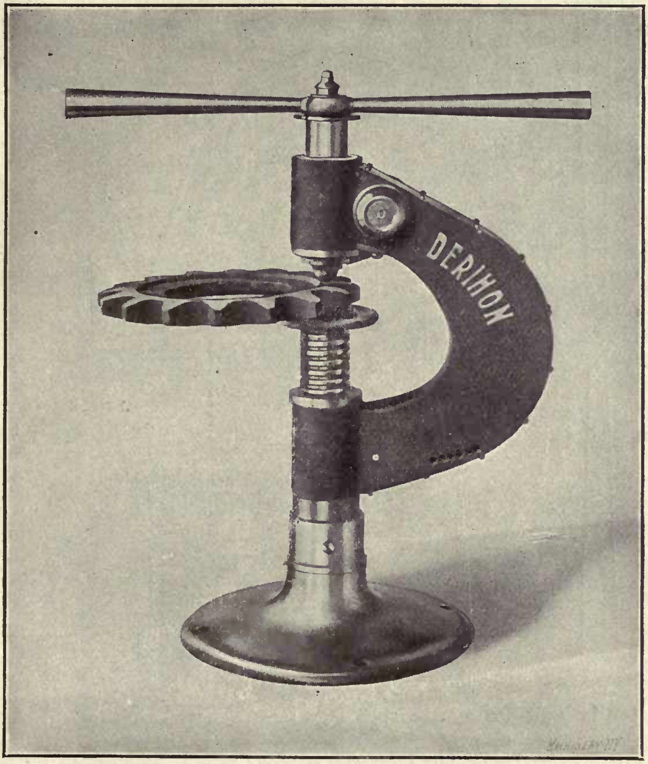


Fig. 6. Portable Press for Testing Hardness by the Brinell Method

A differential screw mechanism is used for applying the pressure. This mechanism consists of the double handle *M*, keyed to the sleeve *D*, which is threaded into the stationary nut *E*, and onto the ram *C*;

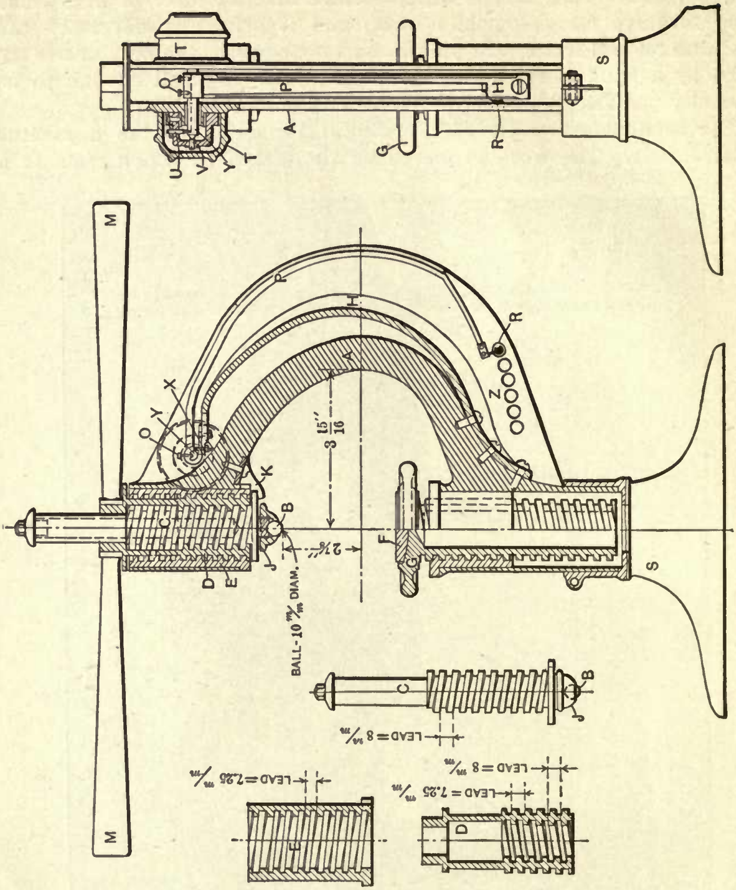


Fig. 7. Details of Design, showing Differential Pressure Screw

this latter is kept from revolving by a stop *K*, which enters a slot cut in the flange, and is provided with a threaded chuck for holding the ball *B*. Sleeve *D* is, it will be seen, the only revolving member of this differential screw. The thread on the inside has a lead of 8 millimeters, while that on the outside has a lead of 7.25 millimeters. This gives an advance of 8 — 7.25 = 0.75 millimeters, or about 0.03 inch per revolution of the levers *M*. The advantage of this construction is, of course, that it gives the effect of a fine thread with a lead 0.03 inch, with the use of threads coarse enough to withstand the great strain to which they are subjected in tightening down the work.

The most ingenious feature of the mechanism is the provision made for gaging the pressure with which the ball is forced into the work. By the arrangement used, the frame *A* of the press itself serves as the spring by which the pressure is measured. As the ball is forced into the work with greater and greater pressure, the frame *A* is deflected and *B* and *F* spring apart. Arm *H* is screwed to *A* at its lower end as shown, but is free at its upper end. Here it is provided with a bearing point *X* close to fulcrum *Y* of pointer *P*. As the frame *A* springs under the pressure, *H*, being free at the upper end, remains undistorted and stationary, while pivot *Y* rises. As pivot *Y* rises, lever *P* swings downward, since it rests only on the point *X* of stationary arm *H*. The lower end of lever *P* is provided with a thin metal disk *R*, which is thus swung in an arc of a circle about center *Y*. A series of holes *Z*, bored in the side of the frame, permit the position of this disk to be seen. These holes are so calibrated that each reads to a definite number of kilograms of pressure when disk *R* is centered with it. Under the extreme tension, when central with the left-hand hole, the reading shows the application of a pressure of 3000 kilograms or 6614 pounds.

The construction of the pivot joint at *Y* is interesting, and is best shown at the right of the engraving in Fig. 7. The hub of pointer *P* is clamped to *Y* by two set-screws *O*, which set in a V-slot cut in *Y*. Two caps *T* are screwed on at either side to protect the bearings of pivot *Y*. Set-screws *V* are adjusted to take up the end motion of *Y*; they do not, however, restrain it in any direction other than the longitudinal. The real bearing is furnished by the points of screws *U* (one at each end) in the bottoms of the V-grooves. These furnish a knife edge or, rather, point support, which gives the utmost freedom and sensitiveness of movement to the pointer *P* and the indicating disk *R*. The various adjustments in connection with this bearing, and the various contact points in the lever system, will be clearly understood from the engraving.

Fig. 6 shows the instrument engaged in testing the hardness of a sprocket-wheel. The simplicity of its use will be immediately appreciated. The sprocket-wheel is placed on the platen, the adjusting screw is run up until the work makes contact with the ball, and then the handles are revolved until the indicating disk is centered with the particular hole in the frame, which shows that the standard pressure has been reached. Handles *M* are then screwed back again, the work is removed, and the diameter of the impression in millimeters measured. This gives the hardness number directly. The whole operation is evidently one of seconds only.

CHAPTER IV

THE SHORE SCLEROSCOPE*

The Shore scleroscope is an instrument in a measure dependent on sensitive touch; or, in other words, it feels the substance much the same as the human fingers. When we touch two or more objects, as, for instance, an orange and an apple, we know that the orange is softer because it yields under pressure more than the apple. We are powerless to measure the hardness of any object that is harder than the finger tips, and there is no way of telling how hard it may be by finger pressure alone.

The sensitive touch of the scleroscope is produced by a tiny hammer dropping from a height of about ten inches onto the metal, hardened steel, etc., which it penetrates slightly. The hammer moves freely, yet snugly, within a glass tube, and weighs about 40 grains. Its striking point consists of an inserted diamond of rare cleavage formation, annealed sufficiently to withstand shocks. This jeweled point is slightly convex and has an area of from about 0.010 to 0.025 square inch. When the plunger strikes the metal to be tested, it reacts or rebounds. The height of this rebound is read on a graduated scale, and an accurate determination of the quantitative hardness of the piece under test is thus obtained.

In the first experiments a steel ball was used as the hammer, but the results were only partially satisfactory. In fact, the inventor was well-nigh on the point of giving up the method when he met the French expert on metals, Dr. Herault. Following out certain of his suggestions, the inventor succeeded in producing a satisfactory instrument for the testing of hardness. The difficulty with the ball-shaped hammer was that it was incapable of striking a sufficiently hard blow to get adequate results, especially with hardened tool steel, so the area of contact was reduced, although the weight was kept large in comparison.

Hardness vs. Elasticity

When the hammer of the scleroscope is allowed to drop with no other force than its own weight, and the point is so flat that absolutely no impression is made on the surface of very hard steel, then the rebound will be about 90 per cent of the fall. This phenomenon is known as the elasticity of solid bodies. Now, since hardness is resistance to penetration, in its clearest definition, it stands to reason that the point of the hammer must be somewhat reduced and rounded. Therefore the relation between the weight of the hammer and its point should be such that when it drops on hardened steel, a permanent impression must always be made, so that if we had not the rebound to go by, the microscope would still show the values. When

---

* MACHINERY, October, 1908, and August, 1909.

the area of the hammer is thus reduced enough to make a permanent impression, a certain amount of the energy stored in the hammer is utilized in doing work. This overcomes the tendency of the metal to resist penetration, depending on how hard it is, or the resistance it offers, and naturally it must rebound considerably less. The hammer always delivers a blow of exactly the same force. If now we get a rebound of 75 per cent on very hard steel, we know that 15 per cent of the hammer's energy was spent in its efforts to overcome the resistance of the steel before it had a chance to react and repel the missile.

The Instrument

While the absolute weight of the entire hammer is little, it is very great relative to the striking area. The hammer has a cylindrical body and is guided in its fall by a glass tube. Great difficulty has been experienced in obtaining tubes with a sufficiently perfect bore. There seems to be no commercial method of manufacturing such tubes, and the method of "test-and-reject" is therefore employed, resulting in a very great amount of waste.

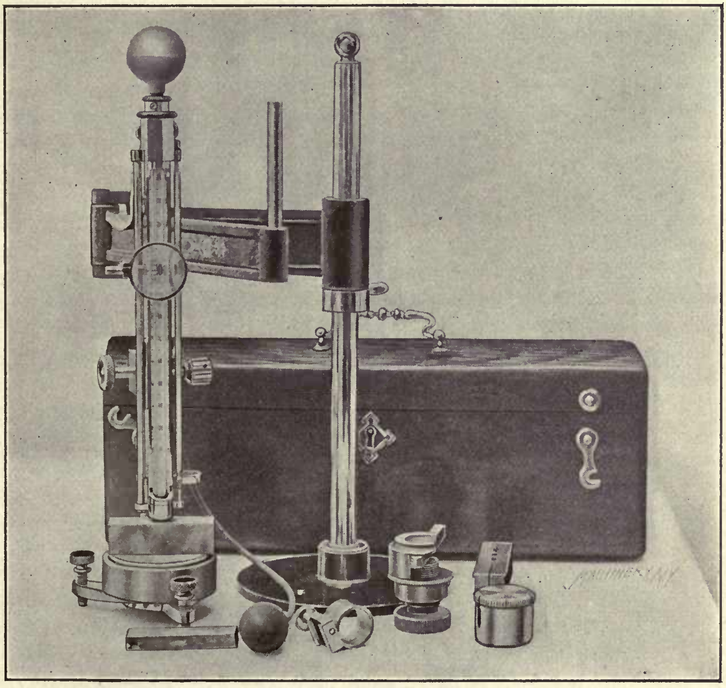
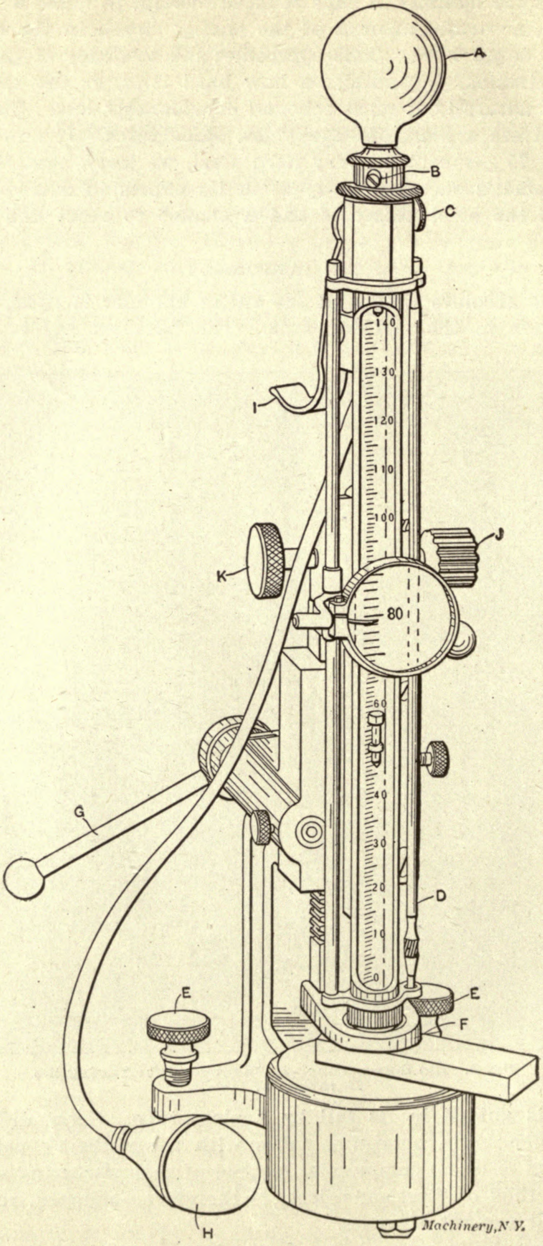


Fig. 8. The Scleroscope—An Instrument for Testing the Hardness of Metals

The glass tube is secured to a frame in a vertical position with the lower end open. The operation of the instrument is very simple. When the hammer is to be raised to the top, the bulb *A*, Fig. 9, is



Machinery, N.Y.

Fig. 9. Detail View of the Scleroscope—an Instrument for Testing the Hardness of Metals

pressed and then suddenly released. This sucks up the jeweled plunger hammer referred to so that it may be caught by a hook which is suspended exactly central in the glass tube and engages with an internal groove on the top of the hammer. Adjusting screws *B* for the hook and its spring are contained in the removable knurled cap. *C* is a cylinder and piston for releasing the hook and hammer by bulb *H* whenever a test is to be made; *I* is a hook which is pressed at the same time and which opens a valve letting in the air and thus preventing the occurrence of a vacuum when the hammer drops. At *J* is shown a pinion knob for moving the instrument up and down independently of the heavy rack and clamp *F* actuated by the lever *G*. At *E* are shown leveling screws and at *D* a plum rod.

When small pieces are to be tested, the scleroscope as shown in Figs. 8 and 9, self-contained with its clamp and anvil, is employed. In using the instrument with the stand the specimen is placed on the table or secured in a holder. It is necessary that the actual point tested should be clean and horizontal and that the piece should be firmly held. If necessary to test more than once, the piece should be slightly moved so as to expose a fresh point to the hammer. The indentation made is, however, very minute, so that several are usually unobjectionable. When the ends of rods, drills, and many other tools are to be tested they are clamped in a bench vise as shown in Fig. 10, and a swinging arm is employed. In this case the instrument is removed from its post on the clamp frame by knurled set-screw *K*, and is attached in the same way to the post on the swinging arm. A kind of female dove-tailed finger ring attached to the clamp on the dove-tail rack bar of the instrument is provided for use in free-hand testing on very large floor work, on parts of machinery being assembled, or on the stock rack, etc. In Fig. 11 is shown how a shaft and box may be tested to determine the relative hardness. From what has been said it is apparent that the apparatus is of universal application.

Instead of dividing the whole length of the fall of the hammer into a scale consisting of 100 divisions, the figure 100 is carried down to a point representing about 68 per cent of the total height of the scale as shown in Fig. 9. This was not an arbitrary provision, but was adopted after consultation with leading metallurgists, one of whom was Dr. Paul Herault, of aluminum and electric steel making fame, of France. These authorities agreed that in the scleroscope hardened steel of average hardness should be taken as the standard with which all other less hard metals should be compared; 100 is the average hardness of hardened steel; 90 is a low value, while 110 is a high value. The scale, therefore, makes it an easy matter to compare the various metals, no matter what their hardness is, and the rebound of the hammer is, therefore, measured against a scale graduated from 0 to 140. This scale is secured in position back of the glass tube. To aid in reading the rebound, a magnifying glass is supplied. After some practice the assistance of this glass may be dispensed with. However, when used, it is secured in such a position as to cover the probable region of the expected reading. The rod to the left of the tube is the support to which the magnifying attachment is secured and along which it is adjusted. The rod to the right of the tube is a plum rod; it swings freely from a point of attachment above, and enables the operator to keep the glass tube vertical.

With the scale graduated from 0 to 140, with hardened steel at or near 100, the hardness of all ordinary materials can be measured. Porcelain and glass, of course, have a higher hardness number than hardened steel, while unhardened steels, brass, zinc and lead have lower and lower degrees of hardness. Unhammered or unrolled lead produces a rebound of only two graduations.

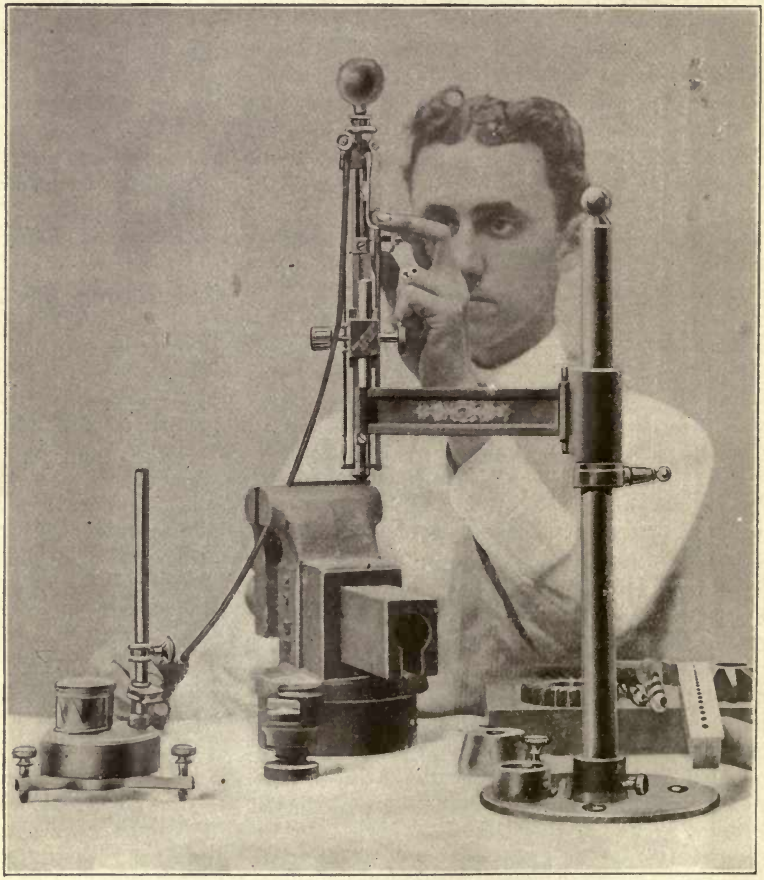


Fig. 10. Scleroscope equipped with Swinging Arm for Testing Pieces clamped in Bench Vise

One of the results of the introduction of scientific methods of precise quantitative measurement of hardness, promises to be in the determination of the relation of the cutting tool to the work to be machined. We are all aware that the tool must be harder; but how much harder? And how express this relation in intelligible language? The scleroscope, it is hoped, will afford a fairly definite answer to this problem. The law has been laid down that the comparative hardness between tool and work as determined by scleroscope readings, should be in the ratio of 3 to 1 or 4 to 1, in order to secure the best commercial results. For example, take the case of work to be machined consisting of a 1 per cent carbon tool steel. Unannealed, such steel is found upon testing to have a hardness varying from 40 to 45 points.

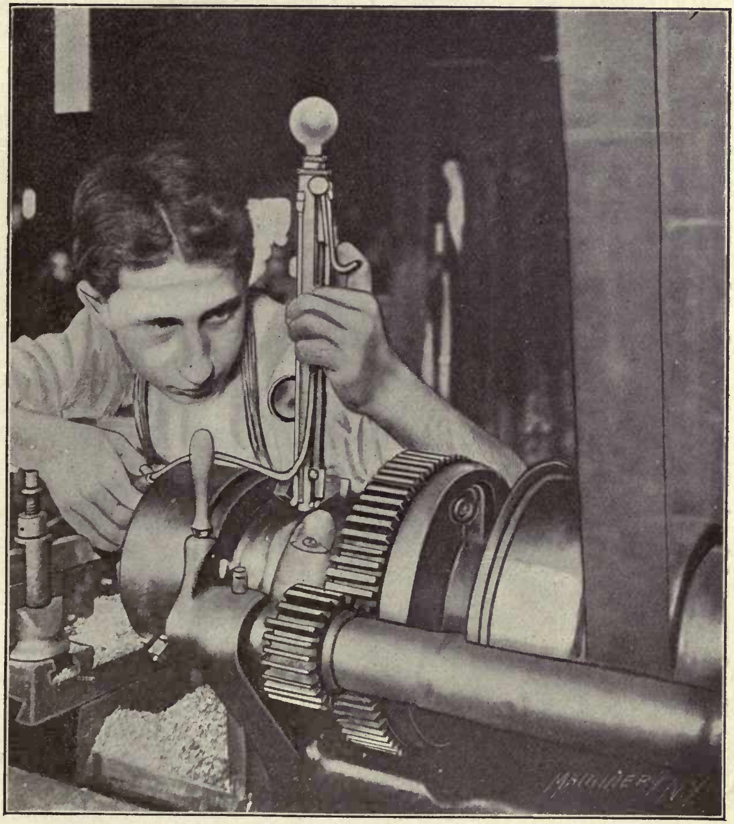


Fig. 11. Shaft and Box of a Lathe being Tested to determine the Relative Hardness

According to the above law, the cutting tool should be at least about 120 to 135 points hard; but the same steel properly annealed, is only about 31 points hard. Consequently, it is not difficult to find a suitable material for the cutting tools. A good quality of carbon tool steel, well hardened, has a hardness of from 95 to 110, and is consequently suitable to cut material of a hardness of 31. Now if this principle as to relative hardness can be thoroughly established for all kinds of metals, an element of certainty will be introduced into shop practice.

Again, it is, of course, to be expected that if two metal parts wear or rub against each other, the harder of the two will cut the softer, whether the difference is small or great, so that it is often important to know whether the more expensive part is really the harder. The scleroscope would seem to afford a means of determining with precision slight differences in hardness, thus enabling the manufacturer to assemble contacting moving parts on the principle of a harder expensive piece in association with a softer cheaper one. Thus in an electrical repair shop, instances may readily be found of the steel shaft cut by the brass box, the box cut by the shaft, and a fairly even wear of both. From an economical point of view, it is much better to have the brasses worn than the shaft, and with such an instrument as the scleroscope it would be possible to predetermine this economically better result. It would seem an easy matter for an automobile manufacturer, say, so to specify the hardness of the gears used, that the gear manufacturer could supply him with a uniform product.

An important application of quantitative hardness tests would appear to be in connection with high-speed steels. Such steels disclose upon testing with this instrument, a hardness varying from 80 to 105. This is at ordinary temperatures, however, and shows scarcely as high a degree of hardness as the best of the pure carbon steels. The effectiveness of high-speed steels depends largely upon the fact that at temperatures of from 600 to 1000 degrees F., at which carbon steels would lose their temper, they retain a high degree of hardness, amounting, say, to 75 on the scleroscope scale. This is sufficient—following the principle of 3 to 1—to do heavy machining on annealed machine steel having a hardness of 25 on the same scale. But if the heat developed by high speed and heavy cuts succeeds in lowering the hardness of the high-speed steel of the tool much lower than 75, then it is no longer an effective tool. It becomes of importance then to test high-speed steels for their effectiveness under temperature conditions obtaining in actual service. It is a comparatively unimportant matter to know that a certain tool of high-speed steel is very hard when cold; what is its condition when hot? By heating the tool to the required temperature, and then testing with the scleroscope, this condition may be determined. Thus the real effectiveness of the high-speed steels may be determined in advance of their use, or even of their purchase.

Amount of Pressure for Indentation

When the hammer falls through a height of ten inches onto hardened steel, it will deliver a striking energy equal to about 20,000 times its own weight, acting through a very short space, of course. With a hammer weighing about 40 grains, and an indentation of, say, 0.002 inch depth, a working pressure of about 100 pounds is obtained. This force acting on a convex point about 1/64 inch diameter, is concentrated. The pressure thus available is about 500,000 pounds per square inch, which is ample to exceed the elastic limit of the hardest and strongest steel in existence.

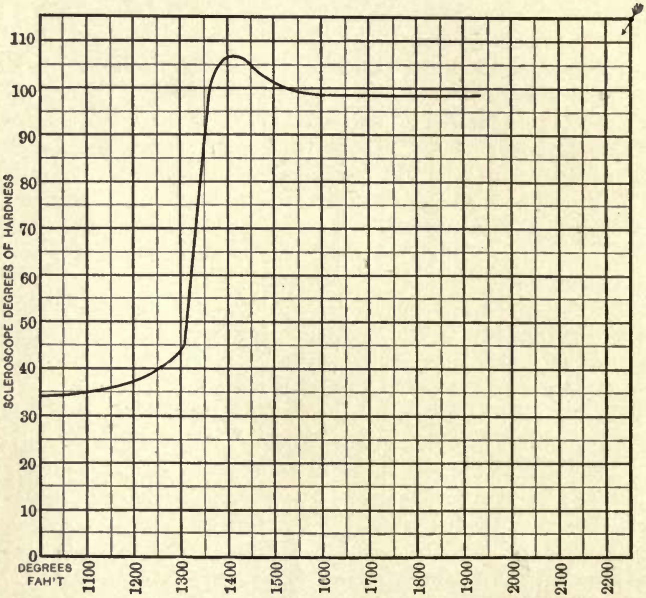
A remarkable feature of this instrument is that it is self-compensating with regard to the energy of the hammer blows on the softer metals. This is due to the yielding of the material and the comparatively slow stoppage of the hammer. In lead, for example, a deep impression is made. This requires a great amount of energy, which is nearly all spent in doing work, and there is very little rebound afterward—about 3 degrees as against 110 for the hardest steel. The constant pressure developed by the hammer is thus only 12 pounds instead of 100 or more for good hard steel, and, of course, the pressures for intermediate hardnesses as on brass and soft or tempered steel are always in proportion to the physical hardness of the brass or steel.

Application to Shop Work

The manufacturer who wishes to get high efficiencies out of his tools will not benefit by the help of such a commodity as the scleroscope in detecting good and bad tools, unless he is willing to amend the errors in practice which he may find. The observation of this principle is the foundation of the success which hundreds of firms in this country and Europe are having with this instrument. While tool work is a line requiring the most careful attention, the material worked and produced is none the less important. In this connection the scleroscope is very commonly applied to industrial systems, with admirable results. An instance may thus be cited showing how these results are obtained.

In 1908, the Brown & Sharpe Mfg. Co. adopted the new method as a guide in the laboratory, particularly for the study and selection of such steel as is required in standard commercial tools. The attention of the company was then turned to its high-grade automobile gears of alloy steels, etc. Meanwhile the Packard Motor Car Co. used the scleroscope to study the past performances of the various gears and parts of old Packard cars, and made careful records. This was also done by many other concerns, and these records showed that alloys, steel or nonferrous metals would give a certain efficiency if the hardness was just right. As the best is, in the end, the cheapest, in high-grade apparatus, the Packard engineers began to issue orders to their various auto part making houses for material which was specified to require a given degree of scleroscope hardness. Gears were made for them by the Brown & Sharpe Mfg. Co. and the Gleason Works, both of whom are using the scelroscope to aid them in filling orders. Wyman & Gordon, who supply forgings to Brown & Sharpe, were able to make them to the required specifications, but, in order to do so, they had to see that the raw material was of the proper hardness. This brings the matter back to the open-hearth or crucible and chemical laboratory, where again the scleroscope is used to great advantage. Before the completion of an automobile of the guaranteed kind, often a dozen instruments are used among the specialty makers who supply the various parts. The ball-bearing manufacturers are required and prefer to test every part before assembling. The Hyatt Roller Bearing Co. and the Hess-Bright Mfg. Co. are obliged to use a number of scleroscopes which are operated by women, carefully trained, who are able to pass on a large number of pieces daily. This testing is to ascertain principally two factors on which success in service depends, *viz.:* the right degree of hardness, and the uniformity of this hardness—and both are equally important. In the latter case it is necessary to test the parts in a number of places, which must be done very rapidly to keep down the additional cost, particularly as in the manufacture of standard parts such as these, there are always losses due to the rejection of some parts which do not conform to the specifications.

The Lunkenheimer Co., the Light Mfg. & Foundry Co,. and other up-to-date manufacturers, use the scleroscope in the standardization of castings adapted to various needs. These houses also make auto parts for the Packard Co., etc., and by the use of the scleroscope are enabled to live up to their specifications. In these auto shops the instrument is used for all classes of work, although it is most needed in the inspection department for the examination of parts and material, particularly of those not made by the builders.



Machinery,N.Y.

Fig. 12. Hardness Curve for Tool Steel of about 0.90 Carbon

Tool Steel and the Scleroscope

Since for most uses (other than for turning or planing tools) plain carbon steel is as yet adequate, many manufacturers have turned their attention to the art of obtaining much higher efficiencies by aid of the scleroscope after good steel has been selected. The method of doing this is interesting, and was first hailed as a revelation by many authorities. Thus, when a steel having a carbon content of 0.90 of one per cent and over is heated to the right temperature and is then properly quenched, the limit of hardness and strength is obtained.

Now, attaining this temperature is such a delicate matter, that unless the very best facilities are at command, anything but the exact heat required may be obtained, and if the heat is too low the tool will be hard only on the edges, while if it is only a trifle overheated such as is regularly done by the average hardener who takes chances by depending on skill of the eye, something like from 50 to 75 per cent of the strength due to rolling or forging is lost. This appalling loss in strength so vitally important in any tool is accompanied by a slight drop in the hardness—not more than 5 per cent. This is detected by the scleroscope as shown in charts Figs. 12 and 13. The former is a hardness curve taken from a tool steel of about 0.90 carbon, while the latter is one taken from a steel having 1.65 per cent. The difference between these curves is indeed very striking and very significant to those who have mastered the elementary principles of the study of tool steels by aid of the scleroscope. The curves are obtained from the Metcalf test as follows: A piece of steel a few inches long and about one-half inch square is heated to a bright yellow on one end and manipulated so that the temperature is less and less toward the other end until a red is scarcely visible. The piece is then quenched in water, ground clean, and tested by the scleroscope at intervals of about ⅛ inch along the bar, beginning at the unhardened end. As each section is tested, a reading is obtained which corresponds with the exact hardness that would be obtained by quenching a similar piece at whatever heat the said test piece had in that location. This

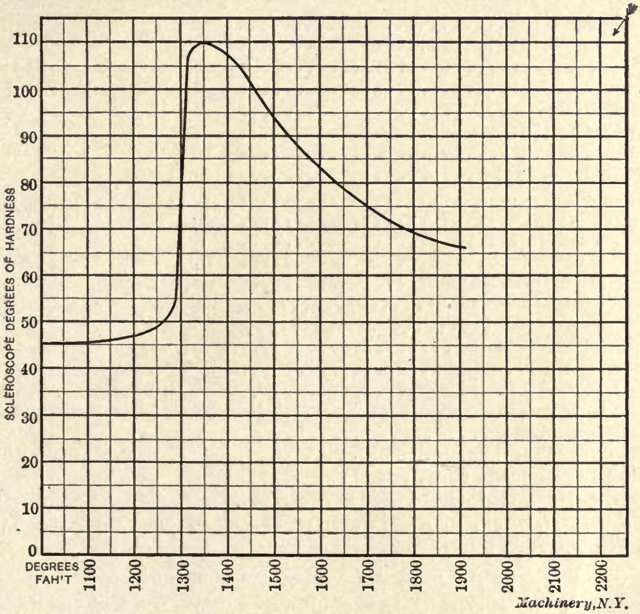


Fig. 13. Hardness Curve for Tool Steel of 1.65 Carbon

hardness number is plotted out on a chart in the usual way so that a true curve is obtained showing the character of the changes in hardness and strength.

The test piece thus obtained represents a stock bar, of the steel which is to be worked into tools, dies, etc., hardened at temperatures that vary more widely than could occur in any well-regulated hardening room, and somewhere within these limits is the temperature that yields the maximum hardness. It supplies an expedient whereby the hardener may know exactly what temperature is most suitable for each tool made from the steel thus tested. His future work is guided and facilitated by stamping on each tool a number corresponding to the hardness number given to the said stock bar. It also enables the hardener or the inspector to intelligently test all hardened tools. Thus, if a die is hardened to 95, we can determine by referring to the test piece of steel, whether this is the highest degree of hardness obtainable with this steel. If the test piece showed the hardness to be, say, 100 or 110, and the die only showed 95, it would indicate that the die did not fulfill the necessary requirements.

SCLEROSCOPE HARDNESS SCALE*

Name of Metal	Annealed	Hammered
Lead (cast)	2—5	3—7
Babbitt metal	4—9	
Gold	5	8½
Silver	6½	20—30
Brass (cast)	7—35	
Pure tin (cast)	8	
Brass (drawn)	10—15	24—5
Bismuth (cast)	9	
Platinum	10	17
Copper (cast)	6	14—20
Zinc (cast)	8	20
Iron, pure	18	25—30
Mild steel, 0.15 carbon	22	30—45
Nickel annode (cast)	31	55
Iron, gray (cast)	30—45	
Iron, gray (chilled)		50—90
Steel, tool, 1 carbon	30—35	40—50
Steel, tool, 1.65 carbon	35—40	
Vanadium steel	35—45	
Chrome-nickel	47	
Chrome-nickel (hardened)		60—95
Steel, high-speed (hardened)		70—105
Steel, carbon tool (hardened)		70—105

Advantage of Testing

It is noticeable in every shop that out of every lot of tools made there are always some "freaks"—tools that are jewels among others—although all are seemingly made alike. Some reamers will hold their size ten times longer than others; lathe tools, particularly thread and cutting-off tools, remain faithful to the setting through thick and thin and are usually kept in reserve for critical jobs. This may be because of defective steel, but usually the good and bad are made from

---

* The figures given are subject to variation, owing to the differences in composition of the metals tested.

the same bar, in which case we must look to our methods of hardening, since the finest steel is most easily ruined, and is thus apt to make the poorest tools.

This latter fact has been known to steel makers for years, and because the abuse of tool steel is so general, none of the finest steels can be procured on the open market, but are made to order only. The explanation of this condition is simple. Tool steel is so sensitive to heat and water that only the photographic plate can be compared to it; it will produce a tool having 100 per cent efficiency only when treated just right. Like the novice in photography who occasionally gets a good picture if his lens is good, so is tool hardening a hit-and-miss process unless the workman be guided constantly. Among many instances noted by the writer, one particularly interesting is the way in which the Winter Bros. Co., Wrentham, Mass., who manufacture taps and dies, undertook to produce tools of the "jewel" variety as a regular product. Some of their taps were used on tough bronze in a turret lathe on a large scale, and often freaks were found which would never break until worn out. The most remarkable of these (7/16 inch diameter) held out three weeks at the rate of 10,000 holes per day as against only a few hours service for some taps. This tap was returned to the maker to be studied by aid of the scleroscope. The stock used was of tempered high-speed steel. The hardness remaining was measured although it was not known what the original hardness was nor exactly what temperature was used to draw it down to that hardness. The manager then ordered that 50 taps be made of high-speed steel and tested by the scleroscope. All these taps were hardened the same as the "freak" sample, and all were tempered with a heat which was variable (in fact it was unknown, except for the average) for the object in view was to get all pieces of the same hardness in the end, which was accomplished. The whole lot was next put to work and watched. After all had been worn out it developed that each tap proved to have the same efficiency as the freak. This resulted in the formal adoption of this method of hardening for taps of this steel and for the class of work mentioned, while other problems involving carbon steel were also gradually being solved along similar lines.

The scleroscope is now regularly used to great advantage in naval construction, in the selection of materials for construction, as castings and forgings, alloys, steel of all kinds and particularly in testing the hardness of projectiles and armor plate. All the United States government arsenals are thus equipped, as well as those of foreign governments, including Japan. Likewise numerous mints and engraving bureaus are guided in their work, in which great economy must be practiced. Similar instruments are also to be found at the Bureau of Standards of Weights and Measures, and the leading railroads are using the scleroscope in their laboratories in the study of newer and superior rails, and rolling stock materials. The scleroscope also works very well on carbon, which fact was first demonstrated by the General Electric Co. All American carbon manufacturers now use it, and every dynamo or motor brush made of this material is first tested as to its suitability for the special work for which it is intended. Applied to glass, etc., it shows at once whether or not the material is too brittle to be good. Wood, rubber and other fibrous materials can only be tested by an especially sharpened drop hammer.

CHAPTER V

THE BALLENTINE HARDNESS TESTING DEVICE

In the Brinell hardness testing method the measuring of the dimensions of the indentation is more or less difficult to accomplish accurately, and the method requires special instruments for obtaining the indentation, and for measuring the amount of depression in the metal tested. In order to overcome this difficulty, a means known as the Ballentine method and apparatus for quickly and accurately determining the resistance to indentation of a material has been devised and constructed.

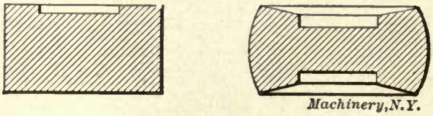


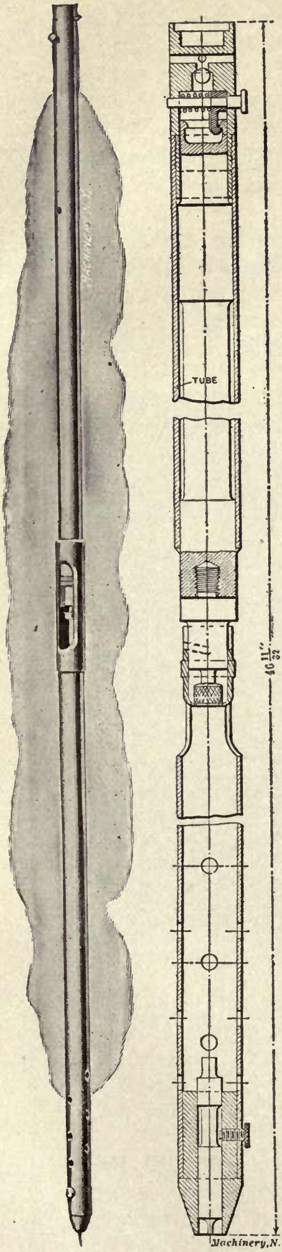
Fig. 14. Lead Recording Disk, before and after Test

The method employed by Mr. Ballentine consists in allowing a hammer of specified weight to fall through a specified height on an anvil to which is connected a pin which rests on the specimen to be tested. An indentation in the material is obtained, but the resistance encountered, instead of the dimensions of the indentation, is measured. This resistance is measured by the blow of the hammer being transmitted to the test pin through a soft metal recording disk located at the lower end of the hammer. This disk affords a constant resistance to deformation, and will be indented to a depth varying in proportion to the resistance the pin encounters in indenting the material tested. The recording disk is usually made from lead.

Figs. 15 and 16 show the general appearance and a sectional view of the apparatus, which consists of a guide tube encasing the drop hammer which at the lower end is provided with a small anvil to which is clamped a lead disk. At the upper end the hammer is held at the top of the tube by a spring latch. At the lower end of the tube a test pin holder is located, in which are inserted the test pins for testing the various materials. The upper end of the test pin holder is provided with an anvil of the same diameter as the one on the lower end of the hammer. A small spirit level is inserted in the top of the tube for leveling the apparatus, and two small slots are cut in the guide tube for inserting and removing the recording disks. The apparatus can be used to test all materials which can be ordinarily machined by steel cutting tools, but cannot be used for hardened steel and similar materials which are too hard to be indented in this manner. Two test pins are provided, one for soft materials such as lead and babbitt metals, and another for harder materials such as iron and steel. The pin for hard materials is very short and small in diameter, while the pin for soft materials is longer and larger in diameter.

The testing can be made either on small test specimens or directly on large parts in process of manufacture, the great advantage of this hardness tester being that it is entirely self-contained and well adapted for either laboratory or general shop use. To make a test it is only necessary to smooth off a surface on the specimen to be tested, and clamp it firmly to some rigid body.

In Fig. 14 is shown a lead recording disk before and after the test. These disks are made within 0.0015 inch of nominal size from a material as nearly of uniform density and hardness as obtainable. The disk is measured with a micrometer before being placed on the drop hammer. When the test has been made, the thickness of the metal between the two recording anvils is again measured, and the difference between the two dimensions will indicate the resistance to indentation or the hardness of the material tested. If, for instance, the disk measured 0.300 inch before the test, and 0.156 inch after test, the difference, 0.144 inch, indicates the hardness of the material, and this hardness would be known as No. 144.



Figs. 15 and 16. General View and Section of Ballentine Hardness Testing Device

CHAPTER VI

THE DERIHON METHOD FOR TESTING THE DURABILITY OF METALS*

In Chapter III is described a portable apparatus for measuring the hardness of metals, designed by the firm of Usines G. Derihon at Loucin-lez-Liége, Belgium. This is used particularly for testing the hardness of metals used in automobile construction, the makers being engaged in the business of furnishing drop forgings for this work. The apparatus illustrated and described in this chapter was devised by the same firm for testing the durability of metals subject to wear. This has also found its greatest use in the hands of the makers in investigating the suitability of various materials for use in automobile construction, for such applications as gears, bearing metals, etc., where durability is a prime requirement.

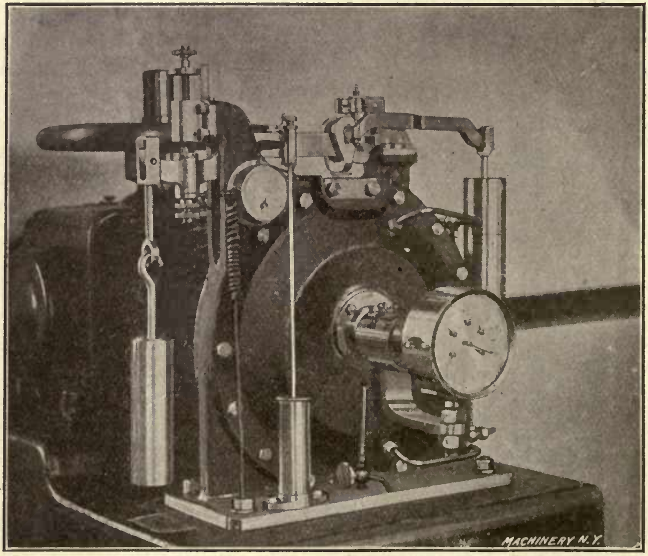


Fig. 17. An Apparatus for Measuring the Susceptibility of Metals to Wear

With this apparatus the metal to be tested is subjected directly to wear under working conditions—that is to say, the wearing is effected by contact with a moving metal surface well lubricated; the only departure from working conditions lies in using a greatly increased pressure to hasten the action. Suitable means are provided

---

* MACHINERY, May, 1910.

for measuring the wear by an accurate micrometer screw. The machine may be used for measuring the friction developed as well, but it should be noted that its specific purpose is that of measuring the rate at which a test piece of any material is abraded or worn away under the conditions imposed.

The apparatus itself is shown in Fig. 17, while Figs. 18 and 19 show the construction. It comprises a casing *R*, in which is mounted a disk *O* of extra hard steel rotated from a motor or other prime mover at a constant rate of speed. A holder *V*, containing the sample to be tested, is pressed down on the periphery of the revolving disk by an accurate and adjustable set of weights, *P* and *Q*. The amount that has been worn off from the sample by the revolving disk is tested from time to time by micrometer screw *K*.

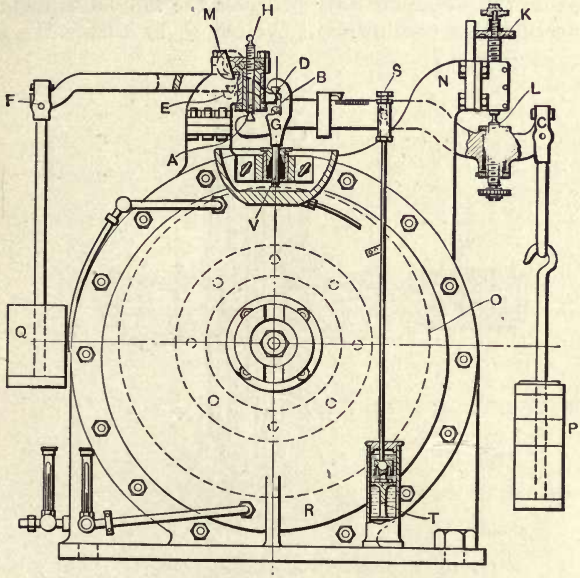


Fig. 18. Elevation of the Derihon "Friction Mill" for Testing

Casing *R* is filled about one-third full of oil to give the condition of lubrication desired. This casing is water-jacketed, space for this being provided at *U* as shown. By regulating the water supply, the temperature of the casing is kept constant so that the factor of temperature does not have to be considered in comparing various tests Disk *O* is one meter in circumference, and may be revolved at from 500 to 3200 revolutions per minute, giving a surface speed varying from about 27 to 175 feet per second.

The test piece is in the form of a small cylindrical plug, set into the square shank *V* of stirrup *G*. This square shank is carefully adjusted and fitted in the stuffing box guide shown, to avoid vibration and oil leakage. Care in the latter particular has to be exercised owing to the high centrifugal force with which the oil is thrown from the revolving disk.

The pressure is applied to the sample by means of weights *P*, hung on the outer end of the lever whose knife edges are shown at *A*, *B* and *C*. The fulcrum is at *A*. This bears on an abutment having a screw adjustment by means of screw *H* and worm *M*; by using this, lever *ABC* may be brought to the horizontal position at the beginning of the test. The upper end of stirrup *G* carries a knife edge *D*, which receives the upward pressure of a lever pivoted at *E* and carrying weight *Q* at its outer end. The purpose of this lever and weight is simply to balance the system before weights *P* are put in place. A sliding scale on the weighing lever provides the fine adjustment necessary for effecting this equilibrium. Weight *Q*, by furnishing another point of contact for stirrup *G* at *D*, serves also to hold the latter firmly in position.

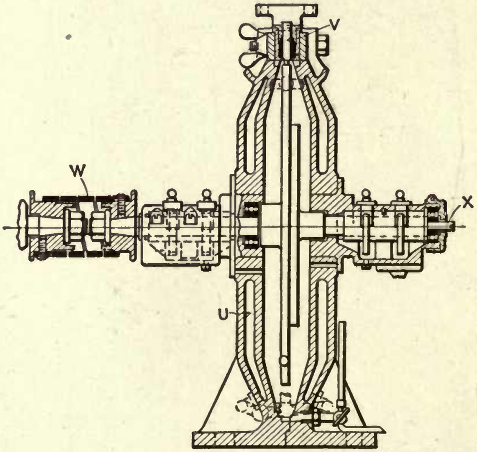


Fig. 19. Section of Device shown in Fig. 17

With the test piece in place in *V*, and the levers set to the horizontal position by adjustment *M*, as described, the first thing to do is to set the micrometer screw to read from zero. Disk *K* being set at zero, screw *L* is turned until the points just come into contact. No dependence is placed on feeling in this matter, as that would not be delicate enough. Instead, screw *L* is insulated from the lever in which it is seated, and is connected by wire with a battery and galvanometer through the frame of the machine. By this means, just as the points of *L* and *K* come into the most delicate contact, that contact is registered on the galvanometer.

When the machine is started up with the micrometer dial *K* thus set at zero, the wear reduces the length of the sample plug of material in *V*, allowing weight *P* to drop. At regular intervals the

COMPARISON OF DURABILITY AND HARDNESS OF VARIOUS STEELS

No. of Sample	Analysis							Breaking Strength	Elastic Limit	Elongation per 100 m m.	Contraction per cent	Hardness Number (Brinell)	Rate of Wear (Derihon)
	Carbon	Manganese	Silicon	Sulphur	Phosphorus	Chromium	Nickel						
1	0.20	1.30	0.50	0.02	0.05	......	......	92,500	54,100	32	64	156	85
2	0.43	0.80	0.30	0.02	0.06	......	......	116,600	71,200	18	50	255	151
3	0.06	0.50	0.02	0.03	0.01	......	......	56,900	55,600	40	70	99	325
4	0.36	1.70	0.16	......	......	......	......	109,500	79,700	20	......	187	57
5	0.38	1.35	0.08	......	......	......	......	126,600	101,000	14	......	187	80
6	0.34	1.20	0.06	......	......	......	......	130,800	105,300	13	......	196	200
7 (No. 2, tempered)	0.43	0.80	0.30	0.02	0.06	......	......	185,000	175,000	......	20	340	89
8 (No. 3, casehardened and tempered)	0.06	0.50	0.02	0.03	0.01	....	......	......	......	......	......	228	25
9 (casehardened and tempered)	0.08	0.33	0.16	0.01	0.01	1.20	4.76	......	......	......	......	444	20
10 (air tempered)	0.28	0.48	0.22	0.01	0.02	1.43	4.55	242,000	227,000	10	30	387	28

amount of this drop is noted by screwing down micrometer screw *K* until the galvanometer again shows contact. Since the ratio of distance *AB* to distance *AL* is 1 to 10 and the graduations on dial *K* read to 0.01 millimeter, actual changes in the length of the test specimen as fine as 0.001 millimeter are read directly, and with accuracy. A dashpot *T* is supplied, as shown, connected with lever *ABC* by spring connection *S*. This steadies the action of the lever, tempering the vibrations and making fine measurements possible. The ratio of distance *AB* to *AC* is 1 to 12, so that the pressure applied is easily found.

The apparatus is shown ready for work in Fig. 17. It is provided, as shown, with revolution counter, galvanometer, and thermometers for indicating the temperatures of the jacket water. A motor is shown direct connected to the apparatus. This may be provided with volt and ampere meters if it is desired to make records of the power absorbed in friction. Since, however, this frictional loss is largely due to the friction between the plate and the oil bath, rather than that between the plate and the test piece, such use is not recommended.

In using this apparatus in testing the durability of metals, some investigations were made to see if there is any relation between hardness as measured by the Brinell apparatus, and durability as measured by this machine. No direct relation between the two characteristics was discovered. The accompanying table gives particulars of a series of experiments along this line. In these experiments the test piece was subjected to a pressure of 48 kilogrammes per square centimeter (682 pounds per square inch), with the friction disk turning at 3200 revolutions per minute or 175 feet per second, for a period of ten million revolutions.

An examination of the table proves that the presence of carbon has an unexpectedly small effect on the resistance to wear as compared with manganese and silicon. This is in accordance with the experience of railroad work, in which rails high in manganese and silicon have been found to wear less rapidly than when these elements are lacking. It would seem that the carbon has practically no effect at all, since half hard steel having a high percentage of manganese and silicon wears much less than hard steel having a small percentage of these two elements. Compare, for instance, samples 1 and 2 in the table, the latter of which was worn out nearly twice as rapidly as the former. Not until this second sample had been hardened, as shown in test No. 7, could it be compared in wearing qualities with sample No. 1.

MACHINERY'S HANDBOOK

For MACHINE SHOP AND DRAFTING-ROOM

A REFERENCE BOOK ON MACHINE DESIGN AND SHOP PRACTICE FOR THE MECHANICAL ENGINEER, DRAFTSMAN, TOOLMAKER AND MACHINIST.

MACHINERY'S Handbook comprises nearly 1400 pages of carefully edited and condensed data relating to the theory and practice of the machine-building industries. It is the first and only complete handbook devoted exclusively to the metal-working field, and contains in compact and condensed form the information and data collected by MACHINERY during the past twenty years. It is the one essential book in a library of mechanical literature, because it contains all that is of importance in the text-books and treatises on mechanical engineering practice. Price $5.00.

GENERAL CONTENTS

Mathematical tables—Principal methods and formulas in arithmetic and algebra—Logarithms and logarithmic tables—Areas and volumes—Solution of triangles and trigonometrical tables—Geometrical propositions and problems—Mechanics—Strength of materials—Riveting and riveted joints—Strength and properties of steel wire—Strength and properties of wire rope—Formulas and tables for spring design—Torsional strength—Shafting—Friction—Plain, roller and ball bearings—Keys and keyways—Clutches and couplings—Friction brakes—Cams, cam design and cam milling—Spur gearing—Bevel gearing—Spiral gearing—Herringbone gearing—Worm gearing—Epicyclic gearing—Belting and rope drives—Transmission chain and chain drives—Crane chain—Dimensions of small machine details—Speeds and feeds of machine tools—Shrinkage and force fit allowances—Measuring tools and gaging methods—Change gears for spiral milling—Milling machine indexing—Jigs and fixtures—Grinding and grinding wheels—Screw thread systems and thread gages—Taps and threading dies—Milling cutters—Reamers, counterbores and twist drills—Heat-treatment of steel—Hardening, casehardening, annealing—Testing the hardness of metals—Foundry and pattern shop information—The welding of metals—Autogenous welding—Thermit welding—Machine welding—Blacksmith shop information—Die casting—Extrusion process—Soldering and brazing—Etching and etching fluids—Coloring metals—Machinery foundations—Application of motors to machine tools—Dynamo and motor troubles—Weights and measures—Metric system—Conversion tables—Specific gravity—Weights of materials—Heat—Pneumatics—Water pressure and flow of water—Pipes and piping—Lutes and cements—Patents.

MACHINERY, the leading journal in the machine-building field, the originator of the 25-cent Reference and Data Books. Published monthly. Subscription, $2.00 yearly. Foreign subscription, $3.00.

THE INDUSTRIAL PRESS, Publishers of MACHINERY

140-148 LAFAYETTE STREET NEW YORK CITY, U. S. A.