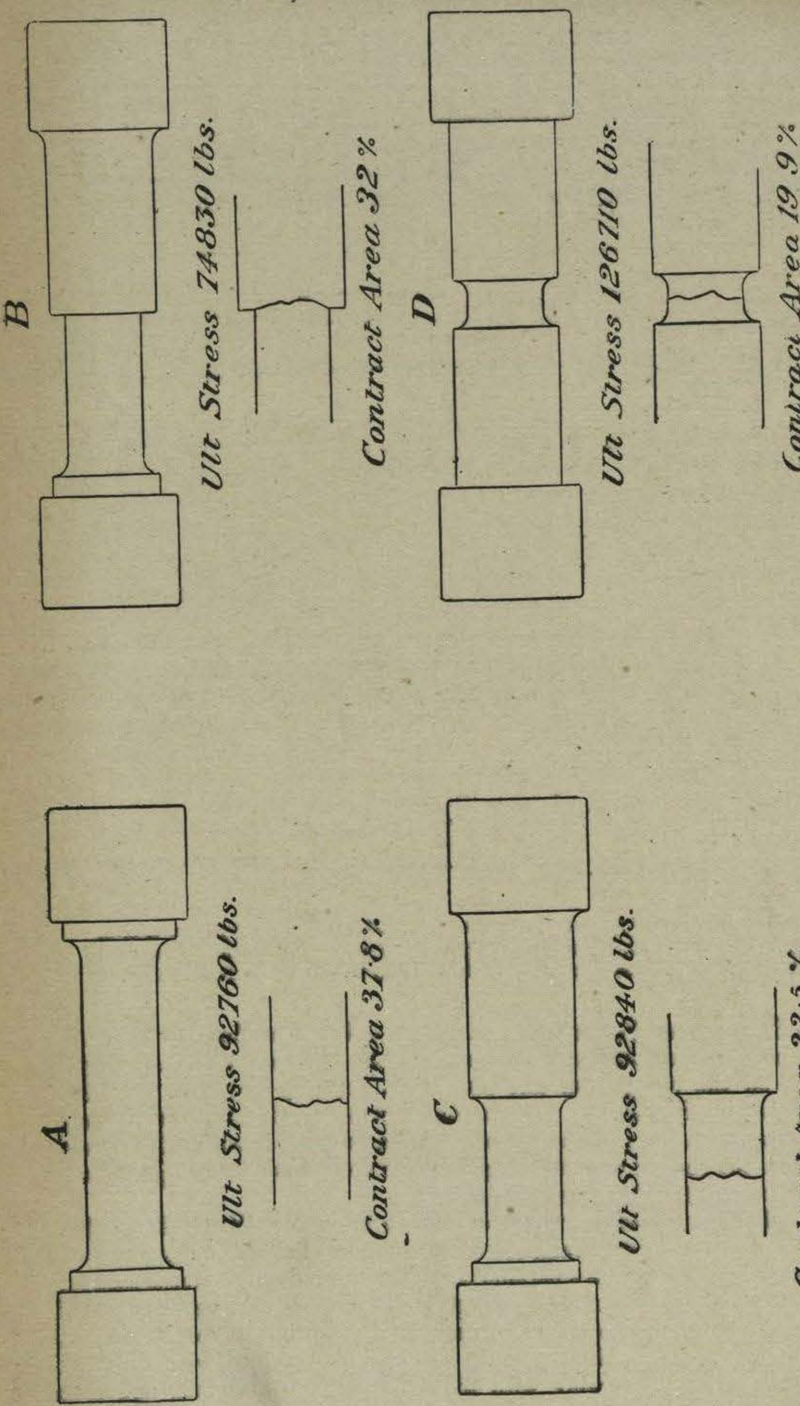

Fig. 218.—Sketches illustrating the influence of the shape of the Test Piece on the Ultimate Stress and Contraction of Area.

The Ultimate Stress of B is less than A by 17,930 lbs., or 19·3 per cent.
„ „ D is more than A by 33,950 „ or 36·6 „

the square corners will not have such a detrimental effect on mild steel as on harder metal owing to the flow of the material. In mild steel, the grooved samples, like D, will give high results, as the contraction of area which precedes fracture is prevented to some extent by the greater mass of metal near the shoulders, but in less ductile materials this influence operates to a smaller extent. In mild structural steel, the flow of metal before rupture extends over a length equal to 6 to 8 times the width of the sample, and if this natural flow is retarded in any way, the maximum breaking load will be increased. Hence it is usual to shape mild steel samples so that at least a 6-inch, and usually an 8-inch or 10-inch, length is left parallel. In harder varieties of steel, such as tires, the parallel portion is frequently not more than 2 inches.

In preparing test bars from plates, or flat bars, angles, &c., it is usually better to shoulder the sample down, leaving the parallel portion of smaller sectional area, as shown in 3, fig. 217; but very good results may be obtained by taking strips of the same sectional area throughout, and this saves some time and expense in preparing the samples. The size and form of test bars which have been adopted by Engineering Standards Committee are given with the Summary of Specifications (p. 500, *et seq.*).

Gauging the Test Piece.—The test piece having been machined to the required shape, the first thing to be done is to take its dimensions accurately. For very rough testing this may be done with a pair of calipers, but a convenient measuring instrument is the screw micrometer, shown in fig. 219. The specimen is placed between the true faces, and the cylinder advanced by turning the sleeve by the milled head until it just touches the test piece, and there is contact without appreciable pressure. There is a graduation along the straight cylinder into tenths and quarter-tenths of an inch, and the edge of the sleeve is itself graduated into 25 divisions, each of which corresponds to the movement of the jaws $\frac{1}{1000}$ of an inch. A certain amount of delicacy of touch is required to get uniform and reliable results with this instrument, but with care it is sufficiently accurate for all ordinary purposes, although for very special scientific work it is better to employ a Whitworth measuring machine. The bar must be carefully gauged in at least three places along its length, and, if anything but a cylindrical bar, both the width and the thickness taken. These dimensions in three places are noted down, and from them the sectional area calculated, and the mean taken. A very fine line is then drawn with a scriber along the surface of the test piece, preferably along the centre of the wide side if a flat bar, and on this at any given distance two very small punch marks are made. The distance between these marks varies with the length on which it is desired to determine the elongation or extension, and may vary from 8 or 10 inches in mild steel to 2 or 3 inches in case of tires or axles.

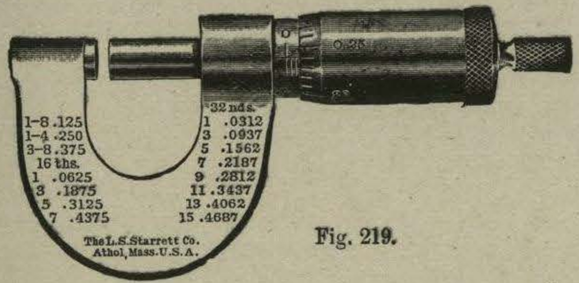

Fig. 219.

Testing the Specimen.—The test piece is now placed in the shackles of the machine and pressure turned on until the beam lifts, when the weight is cautiously advanced along the lever beam to keep it floating in the horizontal position midway between the top and bottom stops, shown in fig. 212, on the top of small standard, *k*, at end of the beam. Assuming the specimen is a soft steel bar, when a load of about 12 to 13 tons per square inch is reached, if a pair of dividers is held on the two distance marks on the surface of the sample, the bar will be seen to stretch suddenly about $\frac{1}{100}$ of an inch, and almost immediately afterwards the beam will drop on to the bottom stop. The commencement of this elongation marks the elastic limit, and the drop of the beam the yield point, although often in commercial testing the drop of the beam is taken as the elastic limit as being more definite, and probably quite near enough for ordinary purposes. The load at the yield point is read off, and the pressure being continued the beam will rise again, and the weight will have to be advanced fairly rapidly to keep the beam floating between the stops. At about 25 to 28 tons per square inch the beam will drop again, notwithstanding that the pressure is full on and no further load is added. The reading must then be taken, as this is the "maximum stress" the bar will bear. The jockey-weight is now run back to reduce the load and keep the lever floating, as far as possible, until rupture takes place at a few tons less than the "maximum load," and this is the "breaking load" on the reduced sectional area. Between the "yield point" and the "maximum stress" the bar stretches very rapidly, and when the maximum load is about reached local reduction of area becomes marked, and the sample rapidly "necks" down at its weakest point, as shown at A, fig. 220, and breaks. When the elastic limit, as distinct from the yield point, is required, instead of depending upon the drop of the beam, it is better for an assistant to stand with a pair of dividers on the elongation points of the specimen, and, directly an appreciable elongation takes place, to take the pressure off and see if the sample returns to its original dimension. If it does, the load can be slightly increased and pressure again taken off, and so on, until the point when permanent set takes place is determined. By this means very accurate determinations of elastic limit can be made, and any error due to the drop of the beam caused by the slipping of the sample is avoided.

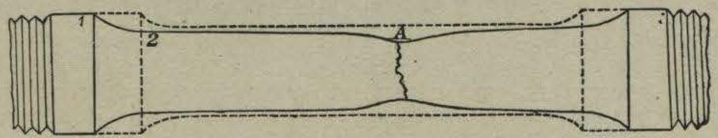

Fig. 220.—Sample of Steel before and after Fracture.

Extensometers.—Although the above method gives very good results for commercial work, when it is remembered that an 8-inch length of mild steel only extends $\frac{1}{1600}$ of an inch for each increase of 1 ton per square inch, if scientific accuracy is required a much more refined method of measurement must be adopted, especially when it is desired to determine the extensions for very small increments of the load. In such work it is often desirable to be able to read any increase in length to $\frac{1}{50000}$ of an inch, and in such cases it is necessary to measure the extensions on opposite sides of the bar and take a mean of the two readings, as any slight bending of the bar would make readings from one side wholly unreliable. These measurements may be made independently by means of mirror micrometers, as in Bauschinger's experiment, but it is generally more convenient to make them indirectly, and several instruments, known as extensometers, have been devised for this purpose. One designed by Professor Unwin gives accurate readings to $\frac{1}{10000}$ of an inch, and more recently Professor Ewing has devised a most beautiful instrument which is capable of indicating an extension of only $\frac{1}{250000}$ of an inch in a test bar.*

The Measurement of Specimen after Fracture.—The specimen after fracture is removed from the shackles, the dimensions of the fractured ends taken with micrometer or calipers, and the reduction of area calculated. The sample is then placed on a flat slab or table, the fractured ends pressed close together, and the distance between the elongation marks measured. The increase in length then gives the elongation which has taken place in 4, 6, 8, or 10 inches as the case may be, and this can be calculated into percentage on the original length. Fig. 221 shows two samples of steel before and after testing, showing elongation and contraction of area.

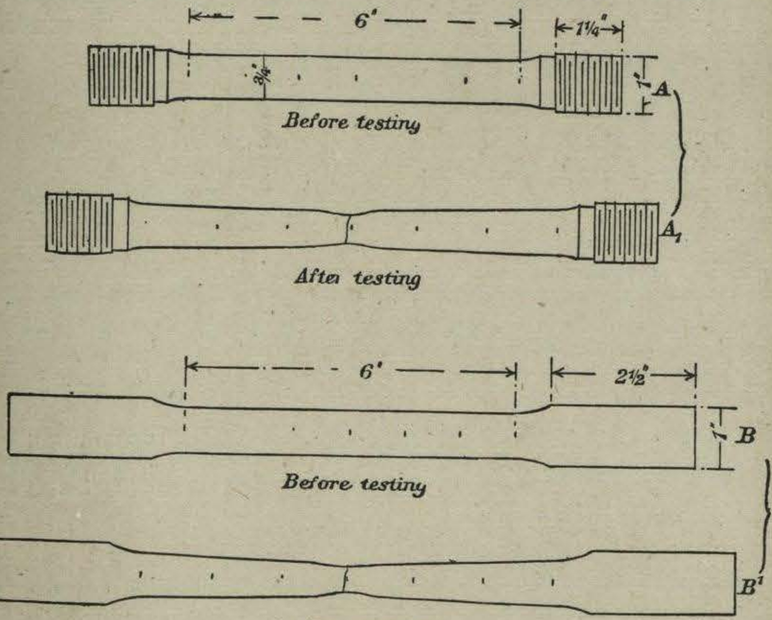

Fig. 221.—Round and Flat Bar before and after Testing.
Bars divided into inches before Testing.

In some cases it may be advisable to mark off the length of the bar into inches, as shown in the sketch, fig. 221, so that the elongation at any given part of the bar may be registered; but this is not usually done, the ultimate elongation being sufficient for ordinary purposes. The total elongation, as has already been pointed out, includes both the elongation which has occurred over the whole length of the bar and the local elongation which has taken place after the yield point has been reached, and the material is in a more or less plastic condition. The ultimate elongation is greater the more suddenly and rapidly the load is applied,† in some cases to a remarkable extent, and long continued stress maintained

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* Ewing, *Testing of Materials*, pp. 75-80.

† Unwin, *Testing Materials of Construction*, pp. 89 and 90.

over a considerable period, say, for several weeks, has a most marked effect in increasing the tensile strength of the material.

The following gives the detailed observation and measurements to be made in testing an ordinary flat bar as shown in the sketches:—

Thickness, mean of 6 readings, ... = 0·4815 inch.
Width, ,, 4 ,, ... = 2·995 inches.
∴ Area = 2·995 × 0·4815 = 1·4421 square inch.
Maximum stress registered by machine, . . . = 50·83 tons.
,, ,, per square inch sectional area, . $= \frac{50·83}{1·4421} = 35·26$ tons.
Elastic limit weight registered by machine, . . = 32·5 tons.
,, ,, per square inch sectional area, . . $= \frac{32·5}{1·4421} = 22·54$ tons.

Contraction of area—
Thickness of plate at fracture, mean of 4 readings, . = 0·368 inch.
Width ,, ,, ,, 2 ,, . = 2·4375 inches.
∴ Contracted area = 2·4375 × 0·368 = 0·897 square inch.

The percentage of contraction in area of cross-section of the bar

$$= \frac{\text{difference between original and contracted area}}{\text{original area}} \times \frac{100}{1}.$$

∴ Percentage of contraction of area in particular case under consideration will be

$$\frac{(1·4421 - 0·897) \times 100}{1·4421} = \frac{0·5451 \times 100}{1·4421} = 37·79 \text{ per cent. contraction of area.}$$

Percentage elongation—
Original length = 8 inches.
Length after fracture = 10·13 ,,

$$\text{Percentage elongation} = \frac{\text{difference between the two lengths}}{\text{original length}} \times \frac{100}{1} = \frac{2·13 \times 100}{8}$$

$$= 26·62 \text{ per cent. elongation in 8 inches.}$$

A load of 1 ton on the bar produced an extension of 0·000415 inch.

The modulus of elasticity may be calculated from the following formula—

$$E = \frac{p \times L}{\omega \times l},$$

where L = original length, 8 inches, ω = original sectional area, 1·442,
p = stress, l = extension measured.

$$\frac{1 \times 8}{1·4420 \times 0·000415} = 13,370 \text{ tons sq. in.}$$

We thus get—

Maximum Stress.	Elastic Limit.	Contraction of Area.	Elongation on 8 inches.	Modulus of Elasticity.
35·26 tons.	22·54	37·79 per cent.	26·26 per cent.	13,370 tons.

In the case of circular or square bars, the calculations are made in exactly the same way. It is usual to describe the nature of the fracture as crystalline, partly crystalline, fibrous, finely granular, &c., according to its appearance. It is important at times to obtain diagrams showing the behaviour of the test piece while under stress, and considerable ingenuity has been shown in devising various instruments for automatically recording, by means of a curve, the elongation, elastic limit, and maximum stress. The curve given in fig. 210, p. 301, was taken by such a recorder at Cooper's Hill.

Compression Tests.—The great bulk of testing done as regards steel in the machines described consists of tensile tests, but for other metals, such as cast-iron columns, and occasionally for steel, compression tests are advisable. In testing steel small cylinders similar to those shown in the sketches (figs. 223 and 224) are taken and subjected to a gradually-increasing load, the specimen being carefully gauged before and after the experiment. Fig. 222 shows the shackle which is used at Cooper's Hill for this work, and the following results were obtained by Mr. Philip Reilly with a sample of steel:—

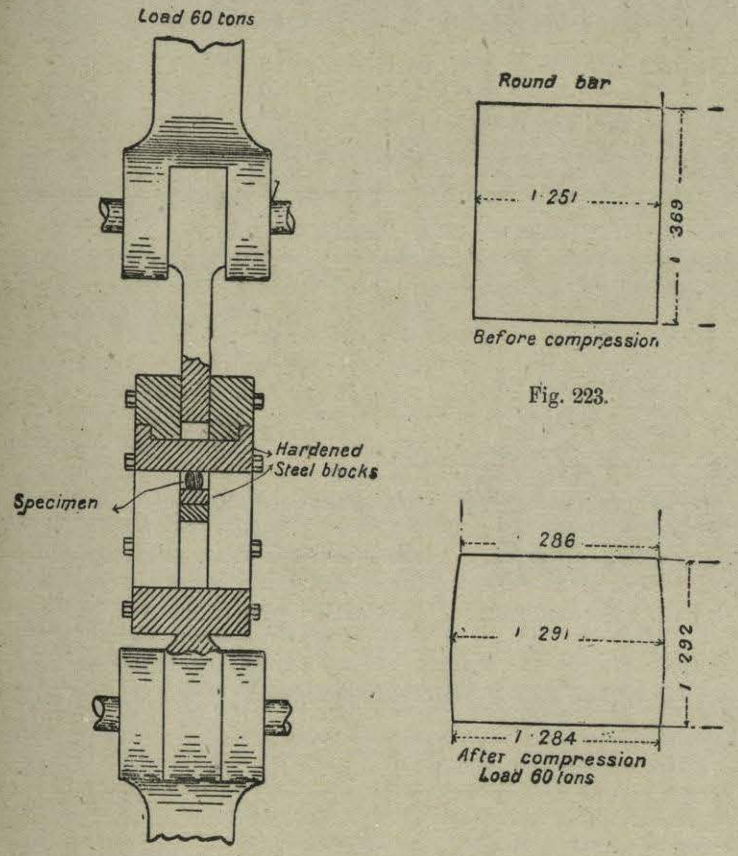

Fig. 222.

Fig. 223.

Fig. 224.

Compression Test.

COMPRESSION TEST ON ROUND BAR STEEL.

Original Dimensions.		Contracted Dimensions.	
Length,	1·367	Length,	1·292
Diameter,	1·251	Diameter,	1·286 end. 1·291 middle. 1·284 end.
Area,	1·229		

Load in Tons.	Length in Inches.	Total Difference.	Total Difference × 50 for plotting.
0	1·367	0·000	0·000
5	1·366	0·001	0·050
10	1·366	...	...
15	1·366	...	...
20	1·365	0·002	0·100
25	1·365	...	...
30	1·363	0·004	0·200
35	1·356	0·011	0·550
40	1·348	0·019	0·950
45	1·337	0·030	1·500
50	1·325	0·042	2·100
55	1·310	0·057	2·850
60	1·292	0·075	3·750

Ordinary Transverse and Shearing Tests.—Transverse tests, except in the form of bending tests, are not usually made in the case of steels, although rolled joists and girders are sometimes tested in this way, and shearing stresses are also sometimes required. Fig. 225 shows one method used at Cooper's Hill in making shearing tests. It is best to have a thread cut upon the bar, A, so it can be screwed through the blocks, C, D, E, shown in the figure, as otherwise the bar is liable to bend away from them.

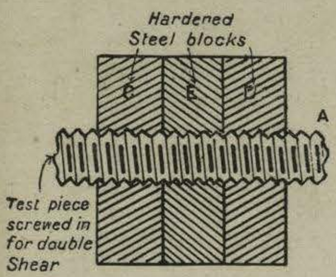

Fig. 225.—Shearing Test.

These blocks fit into a shackle similar to that used for compression, and when the pressure is put on, the centre block, E, remains fixed, and the side blocks, C, D, are forced down and shear off the ends of the sample. As both ends are sheared off, the actual area sheared is double the area of the bar, and the calculation is as follows:—

Diameter, 0·654.
Area, 0·336 square inch.
Being in double shear area 0·336 × 2 = 0·672 square inch.
Sample sheared at 19·4 tons on the beam.
Equal to 28·87 tons per square inch.

The Wicksteed machine described on p. 303 is specially designed for transverse testing of large beams, joists, and girders, and much useful information may be frequently gained as to the weak portion of any given section, and where it requires stiffening. In this machine 18-inch joists can be readily tested.

Torsional Tests are frequently made on wires, but these are rarely required for structural steel specimens. A special attachment for this purpose has been designed and is supplied by Messrs. Buckton for use with the Wicksteed machine, but is hardly of sufficient importance to metallurgists to need description here.

Variation in Strength of Specimens from same Plate, Bar, &c.—It is a well-known fact amongst practical men that if a strip be taken from a plate as rolled, cut in two, and the one tested as rolled and the other machined and then tested, that the former will give a higher ultimate or maximum stress probably owing to the more highly compressed material

on the outside. It has also been found that considerable variation may occur in material if comparative tests are taken from different parts of a large bar, the outside giving a distinctly higher maximum stress than the centre. In the following table* Campbell gives some results showing a difference of over 2 tons between the outside and the centre of forged rounds:—

TABLE LVIII.—Physical Properties of Test Pieces ¾ inch in Diameter cut from Forged Rounds.

Size of Ingot, 18 × 20 inches. Pennsylvania Steel Company, 1893.

Diameter of Forged Round.	Place from which Test was taken.	Ultimate Strength, Tons per Sq. In.	Elastic Limit, Tons per Sq. In.	Elongation in 8 Ins., per Cent.	Reduction of Area, per Cent.	Elastic Ratio, per Cent
8 ins.	At a depth of 1 inch from outside, ...	28·00	14·67	21·50	40·4	52·4
	At a depth of 2 inches from outside, ...	25·93	13·02	22·25	37·5	50·2
	The central axis, . . .	25·93	14·05	20·25	34·1	54·2
10 ins.	At a depth of 1 inch from outside, ...	29·49	16·55	19·50	33·9	56·1
	At a depth of 2½ inches from outside, ...	28·01	15·92	18·00	32·7	56·8
	The central axis, . . .	27·18	14·34	19·50	23·8	52·8
	Preliminary test of same heat from 6-inch ingot, . .	28·54	18·86	26·25	41·7	66·1

These differences may be due to some extent to variation in the chemical composition due to segregation, but as it occurs in cases where the material is of very highest quality, in which segregation would be small, such as axles and tires, this is not sufficient to explain the facts, and it is more probably due to the surface being more compressed by forging or rolling, and to the different rates of cooling of the outside and inside. Whatever its cause it shows the importance, both in the interest of engineers and manufacturers, of a general agreement as to what part of a bar a sample shall be cut from if concordant results are to be obtained. When working to specification it is usual for manufacturers to roll down a bar from a small ingot, as a preliminary test, to assist in the classification of the metal, but owing to the varying amount of work and the finishing temperature, these bars always differ to some extent, and often to the extent of 2 to 3 tons per square inch from the specimens cut from the finished section. There is no doubt that the amount of work has some influence on the strength of the material, but probably not so much as was formerly supposed. This is a matter largely within the control of the steel maker, and he must arrange to cast his ingots of such a size that sufficient work is put upon them, in producing the finished article, that they will have the required mechanical strength and soundness, although it must be recognised that it is not possible to ensure the same amount of work on large that it is on small sections.

Although the testing machine is able to afford much information as to the properties of steel for various purposes, it tells us nothing as to its

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* Campbell's *Structural Steel*, p. 220.

welding qualities or its behaviour in forging or hot working at different temperatures, and only incidentally gives evidence as to its power of resisting fracture from loads applied suddenly, and consequently additional tests have often to be made.

Various tests have been proposed from time to time with a view of supplementing the information obtained by the ordinary Static method of testing, and amongst the most useful are (1) Hardness tests, (2) Impact tests on notched or plain bars, (3) Alternating impact and repeated bending tests.

Hardness Tests.—The best known method for the determination of hardness is the Brinell, which determines the resistance to penetration which the material offers when a hardened steel ball of given diameter placed upon it is subjected to a definite load. The depth of the impression is not measured direct, but the diameter of the cavity is accurately gauged by means of a microscope fitted with a millimetre scale, vernier, and crosshair. From this the spherical area is calculated, and the maximum load in kilogrammes divided by the area gives a hardness number.

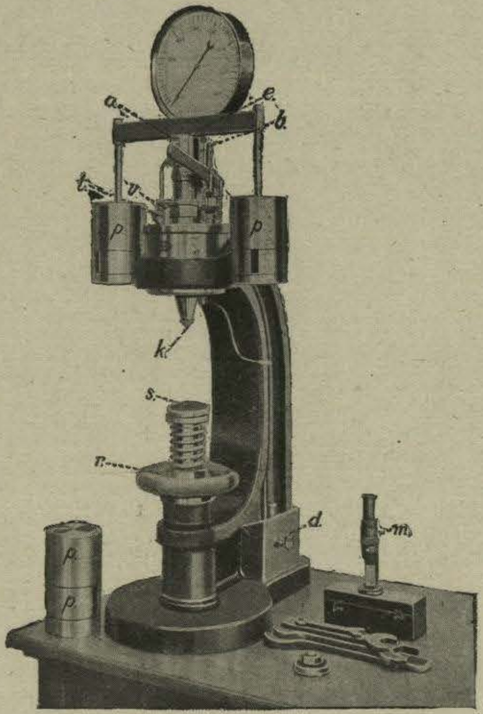

Fig. 226.—Brinell Ball Testing Machine.

Fig. 226 shows a machine specially designed for carrying out this test.

It consists of a hydraulic press acting downwards, the lower part of the piston being fitted with a 10 mm. steel ball, *k*, by means of which the impression is made on the surface of the specimen or object to be tested. The sample is placed on the support, *s*, which is vertically adjustable by means of the wheel, *r*. The table at the top of the support can be more or less inclined to enable the upper surfaces of irregular-shaped specimens to be made quite horizontal when testing. The whole apparatus is solidly mounted on a cast-iron stand.

The pressure is produced by means of a small hand pump, and is recorded in kilogrammes on a specially graduated pressure gauge.

In order to render the motion of the piston quite frictionless, packings are dispensed with, for, as the piston is so accurately fitted, they are unnecessary.

Any small quantity of fluid escaping is collected by means of a pipe conduit in a receptacle, *d*, at the foot of the stand, whence it is poured through the funnel, *t*, to the oil reservoir.

In order to guard against any error of the gauge, the machine is fitted with a special contrivance which checks the indications of the gauge, and at the same time serves to prevent any excess of pressure beyond the exact amount required, which may be varied at will from 500 to 3,000 kilogrammes by increasing or decreasing the weights, *p*.

This controlling apparatus consists of a smaller cylinder, directly communicating with the main cylinder, which is furnished with a frictionless piston. When this is loaded with weights corresponding to the amount of pressure required, the piston is pushed upwards at the very moment when the required pressure is attained.

A test specimen must be properly planished by file, grindstone, or emery wheel, on the place where the impression is to be made, and then be placed on the support, *s*, which is raised by means of the handwheel, *r*, until it comes into contact with the ball, *k*. On then closing the valve, *v*, which cuts off communication between the press cylinder and the oil cistern, and applying a few slow strokes with the hand pump, the pressure needed to force the ball downwards will be produced, thereby causing a slight impression in the sample of metal. As soon as the requisite pressure is attained, the upper piston with the controlling apparatus is forced upwards, whilst the corresponding pressure is indicated by the gauge.

On testing specimens of iron or steel, the pressure must be maintained for about 15 seconds, but in the case of softer material, during about half a minute. After the impression is made the pressure is removed, and the sample at the same time released by re-opening the valve, *v*, and lowering the support, *s*. The communication is thus restored between the cylinder and the oil cistern, and the spiral spring fitted within the cylinder, being of just sufficient strength to overcome the weight of the press piston, pulls it upwards into its original position, whilst forcing back the liquid into the cistern. The diameter of the impression produced by the ball is then measured, and the corresponding hardness numeral looked for in the table.

The best way of measuring the diameter of the depression is by using the microscope, *m*, which is specially made for that purpose, and which gives results accurate to within $\frac{1}{20}$ millimetre.

The hardness numeral is ascertained by dividing the maximum pressure by the spherical area of the concavity.

The rule for calculating the hardness numeral is as follows:—

Radius of ball, ... = r
Diameter of depression, ... = D
Superficial area of the depression in mm., . . = y
Pressure on ball in kilogrammes, ... = K
Hardness number . . . . = H

$$2\pi r\left(r - \sqrt{r^2 - \frac{D^2}{4}}\right) = y. \qquad \frac{K}{y} = H.$$

EXAMPLE.—Let $r = 5$ mm. $D = 4$ mm. $K = 3{,}000$ kilogrammes.

$$\text{Then } 2\,\pi\,5\left(5 - \sqrt{25 - \frac{16}{4}}\right) = 13{\cdot}13 = y \text{ and } \frac{3{,}000}{13{\cdot}13} = 228 = H.$$

Several other methods of determining hardness have been proposed, one of the most recent being the sclerometer. In this instrument a hard steel ball is allowed to fall from a definite height upon the surface of the specimen, and the height of the rebound is registered. This is said to be a measure of the hardness, and no doubt when dealing with similar material comparative results are obtained, but other properties, such as the elasticity of the body under examination have an important effect, and must be taken into consideration before drawing conclusions from results with different classes of steel.

Impact Tests.—During recent years very many methods have been devised by engineers for testing metals by impact, with a view of showing up weaknesses under sudden shocks or alternating stresses, which are not clearly indicated by the ordinary tensile tests.

The methods at present more or less used by engineers and metallurgists may be divided broadly into the following classes, according to the number and position of the notches and supports and method of applying the load.

(1) One notch in the centre of the bar: two supports: fracture effected by a series of blows of a falling weight (*Seaton* and *Jude*).

(2) One notch in the centre of the bar: two supports: fracture effected by one blow of a falling weight (*Fremont*).

(3) One notch, not necessarily in the centre of bar: one support: fracture effected by one blow on overhung portion from a falling pendulum or weight (*Izod*).

(4) Two opposite notches, not necessarily in the centre of bar: one support: fracture effected by a series of blows of a falling weight on overhung portion (*Brinell*).

(5) Same as (4), but with an arrangement for reversing the bar after every blow (*Kirkaldy*).

The following is a description of the method of applying the test in the case of methods (1), (3), and (5):—

In the Seaton and Jude method a bar is taken, 4 inches long and ½ inch square in section, and a V notch ⅛ inch deep is cut in the centre of one side. The bar is supported on a bearing at each end, the notch being downwards, and is broken by a series of blows from a falling weight striking it on the centre. The weight and height of drop can be varied according to the metal under test. The energy absorbed in breaking the samples is calculated into foot-pounds. In the case of ductile steels requiring a number of blows, say seventy or more, the actual energy absorbed can be obtained to within one blow—that is, one-seventieth or so of the total energy—but in the case of brittle steels requiring only one to three blows, the error is still one blow, equal at least to one-third of the total, or even if one-half the last blow be taken as the breaking weight, the error would still be one-sixth of the total.

In the Izod method, the test piece is $2 \times \frac{3}{8} \times \frac{3}{16}$ in. and has a shallow V notch on one side; this is supported at one end in a clip or vice and held vertically. Fracture is effected by one blow of a pendulum striking the overhung portion, and the residual energy in the pendulum is measured by the arc through which it swings after fracturing the sample. In this method an exact measure of the energy expended in fracturing the sample, within a very slight error, is obtained.

In the Kirkaldy method, the test piece is of the same dimensions as that used by Seaton and Jude, but instead of the V notch, it has two opposite circular grooves, each ⅛ inch deep at the centre of the bar. The test bar is supported in a suitable block or vice at one end and fractured by a series of blows from a falling weight on the overhung portion, but after every blow the entire block is turned over by a cam attachment, so that blows are delivered alternately on each side of the test bar. In this method, as in the Seaton and Jude, the force required to fracture the bar is calculated into foot-pounds, and the degree of accuracy largely depends upon the number of blows which are required to produce fracture; owing, however, to the falling weight being a small one, the number of blows required to produce fracture, even in very brittle steels, is comparatively large, and consequently the error is not very considerable, and in moderately ductile steels is inappreciable.

In all the above methods notched bars are used to locate the point of fracture, and the results obtained largely depend upon the form of the notch. Even when this is made of exactly the same form with every possible care duplicate tests often give widely different results, due possibly to some slight local difference either in micro-structure or other physical conditions of the material at the bottom of the notch.

The author has recently examined the above methods of impact testing with notched bars of different classes of steels, and, in view of the irregularities disclosed when using the same machine for testing duplicate specimens of the same material, considers it to be a serious question how far methods showing such variations should be relied upon by engineers to differentiate between the physical properties of different materials. Small samples, in no case exceeding ½ square inch section, were used in these experiments, and probably if larger bars not less than 1 inch square had been used more concordant results would have been obtained.

Several types of impact testing machines have been designed by Stanton and Bairstow * of the National Physical Laboratory, and are described in a paper read before the Institution of Mechanical Engineers, and have proved useful in the detection of brittleness and low elastic resistance in materials.

Some very interesting results of the testing of *unnotched* bars, *in the direction of their length*, so that the whole cross-section is subjected to the impact stress, were lately given in a paper read before The Society of Mechanical Engineers.† The machine is designed to fracture the bar at one blow, and the energy remaining in the tup immediately after rupture is determined by a very ingenious arrangement. The tests so far carried out have been made on commercial steels of good quality, and further experiments are in hand on inferior steels to see how far this method is capable of differentiating between steels of different quality, and the results will be watched with considerable interest.

Much work has been done by Breuil and others on impact testing, and the general concensus of opinion seems to be that to obtain satisfactory results unnotched bars will have to be employed.

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* *Inst. Mech. Eng.*, Nov. 1908.

† "Comparison of the tensile, impact tensile, and repeated bending methods of testing." *Institute Mechanical Engineers*, Feb. 27, 1910. Blount, Kirkaldy, and Sankey.

Alternate Bending and Impact Testing.—The earliest form of machine was an alternating bending machine designed by Wohler, in which the test bar was fixed in a rotating chuck, a weight being suspended at the free end of the bar; by this means every revolution of the bar produced two reversals of stress, and as the bar could be rotated at a very high speed, a large number of alternations could be obtained in a given time, which could be readily recorded by a counter; the stress could be varied by increasing the pressure or weight at the end of the bar, but all Wohler's experiments were carried out with a stress below the elastic limit, which meant a great many revolutions and expenditure of much time to obtain the result from one specimen. Various modifications of this form of machine have been tried, but unless the stress is maintained below the elastic limit the results are not satisfactory, and if this is done the time required for each test is too long for the method to be adopted in every-day practice.

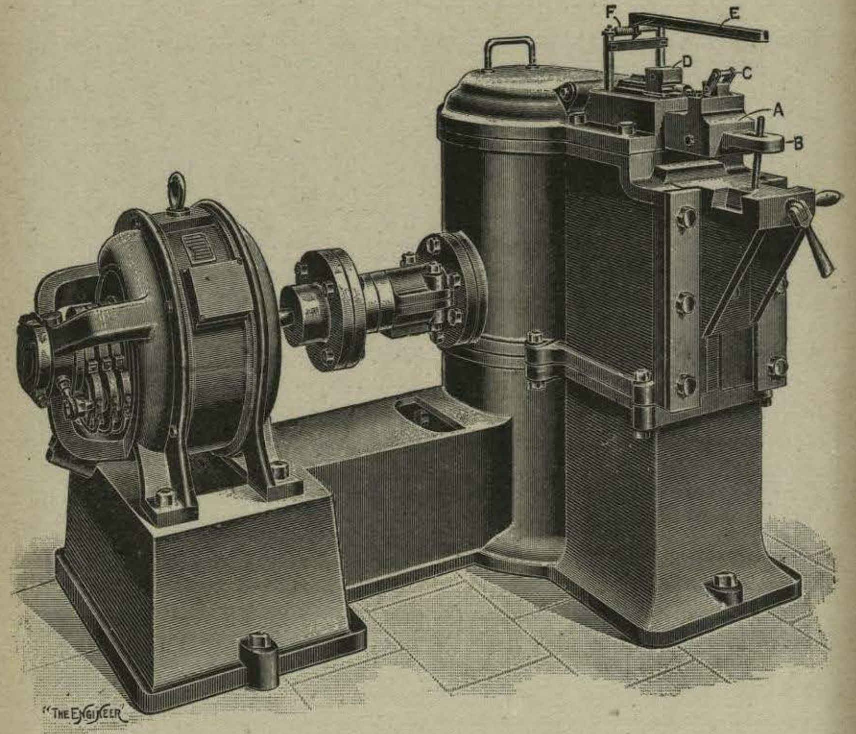

Fig. 227.—Arnold Alternating Test Machine, with Motor.—A, Ram; B, sliding plate; C, catch; D, speed counter. The bar E is attached to the test piece by a wire (not shown in the illustration), and when the test piece breaks the counting automatically stops.

Some years ago Dr. Arnold proposed an alternate bending test, in which the specimen was rapidly bent backwards and forwards through a definite angle by means of a blow, so that the test piece was not only subjected to bending, but also to shock. After a considerable number of experiments he designed a machine to carry out this test under standard conditions, and this machine with and without a motor is shown in figs. 227 and 228. A standard bar, 6 inches long by $\frac{3}{8}$ inch diameter, is held rigidly in a die, and a slotted bar, A, moving backwards and forwards, strikes it first on one side and then on the other, and bends it through the required angle until fracture takes place, the number of alterations being recorded by a speed counter, D, which automatically stops when the sample breaks.

The standard conditions which have been adopted are as follows:—Rate of alterations, 650 per minute; distance from plane-cutting zero of bending moment to plane of maximum bending moment or stress, 3 inches; deflection at zero of bending moment, $\frac{3}{8}$ of an inch each way; size of test piece polished bars, 6 inches × $\frac{3}{8}$ inch diameter. The plane of maximum bending moment is the face of the die, and the zero of bending moment is in a horizontal plane through the point of contact of the test bar with the slotted bar. Prof. Arnold states that, given even texture, results agree to within two (or even one) alteration, and the slightest difference in the texture of a steel is shown either by the grey tension line in the fracture being off the zero of stress in the plane of maximum bending moment, or in very bad cases by the rupture taking place above the plane of maximum bending moment or stress, as much as $\frac{1}{2}$ an inch above the die line.

Fig. 228.—Arnold Alternating Test Machine.

Captain Sankey* has recently designed an alternate bending machine, which not only automatically records the number of bends before fracture, but the bending effort of each bend. The machine, illustrated in fig. 230, and diagrammatically in fig. 229, consists of a small bed-plate arranged to bolt down to a bench, at one corner of which there is a grip, A, for securing one end of a flat steel spring, B. The other end of the spring is fitted with

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* *Inst. Mech. Engineers*, "Comparison of tensile, impact tensile, and repeated bending methods of testing steel," by Blount, Kirkaldy, and Sankey, May 27, 1910.

a special grip, C, for holding one end of the test piece, D. The other end of the test piece is fixed into a handle, E, about 3 feet long, by means of which it is bent backwards and forwards through the "standard" angle. An indicator, F, is provided to show this standard angle. Alongside of the spring, and fixed to the bed-plate, there is a horizontal drum, G, to carry the recording paper, and the pencil, H, has a horizontal motion actuated by the motion of the grip, C, and conveyed by the steel wires, L and M, and the multiplying pulley, N, the wires being kept taut by the spring box, O. The zero line is in the middle of the paper, and the pencil, H, moves in one direction when the bending is from right to left, and in the opposite direction when it is from left to right. The drum has a ratchet wheel, K, with a detent (not shown) worked by the motion of the pencil carrier. The result of the combined motion of the pencil and of the drum is to produce an autographic diagram. Obviously the greater the stiffness of the test piece the more the flat spring, B, will have to be bent before its resistance is equal to the resistance to bending of the test piece. Hence the motion of the pencil is proportional to the effort required to bend the test piece.

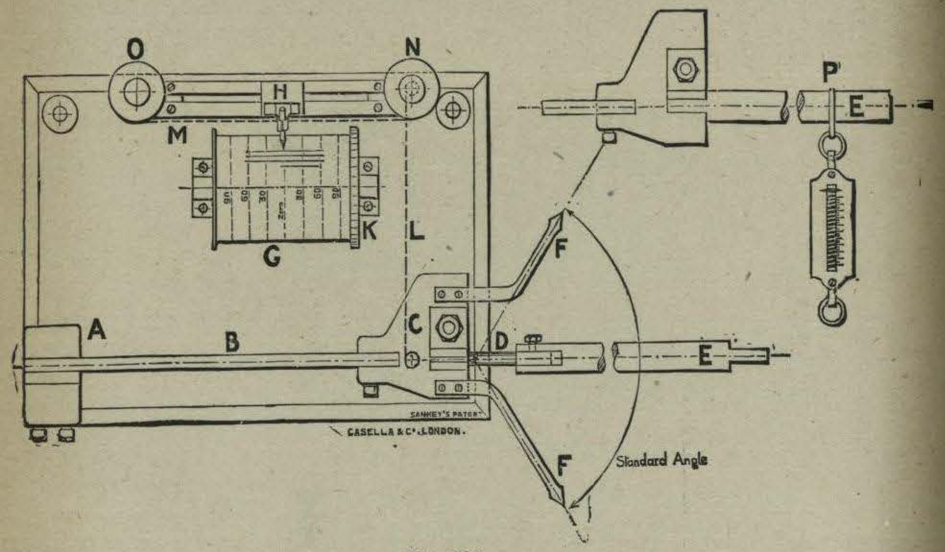

Fig. 229.

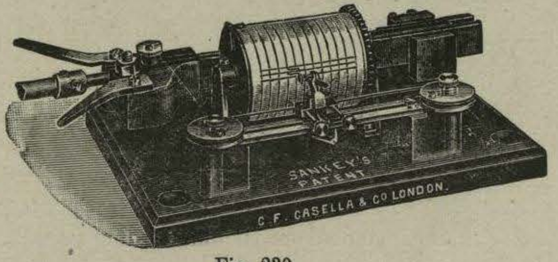

Fig. 230.

Working the Machine.—The test piece is properly secured in the handle, E (fig. 229), by means of the set screw, it is then inserted into the grip, C, and the free length ($1\frac{3}{4}$ inches) is adjusted by means of a gauge provided for the purpose, after which the grip, C, is tightened. The first bend is taken to the left until the mark on the handle coincides with the pointer indicating the "standard" angle. The bending is then reversed, and the test piece is bent until the mark on the handle coincides with the second pointer. The bending is again reversed, and so on until the specimen breaks. The point at which the test piece breaks should be noted in decimals of one bend, which are marked on the indicator.

Calibration.—The record papers are graduated in pounds-feet, and to calibrate the machine the flat end of the lever is to be inserted in the jaws of the grip with the shoulder well up against the face of the grip, a blank chart should be placed on the drum, and the pencil set with its point on the zero line. A reliable spring balance is then attached to the peg provided for the purpose at the other end of the lever, and such pulls applied as may be necessary to cover the range of readings on either side, noting in each case the point reached on the paper by the pencil. Thus, if a pull of 20 lbs. is applied, the bending effort exerted is $20 \times 3 = 60$ pounds-feet, since the lever arm is 3 feet, and in this case the pencil point should be exactly on the 60 pounds-feet line. Should the points reached by the pencil on the chart not coincide with the pulls applied to the end of the lever, adjustment is to be effected by altering the position of the side spring plates placed on either side of the main spring. Each side should be adjusted independently. The calibration should be made after the wire has been adjusted by means of the spring box. This is important, because the calibration depends on the tautness of the wire. After inserting a new wire, the calibration should be repeated a few times until the wire has taken a permanent set.

The "standard" angle is so fixed that the distance travelled along the arc of the circle 1 foot radius from the point of bending the test piece is 1·60 feet (this angle is $91\frac{1}{2}$°). Hence, by multiplying the bending effort (in pounds-feet) by 1·6, the energy (in foot-pounds) required to make a complete bend, is found.

Generally, the stronger the material the less the number of bends it will endure, and approximately it may be assumed that, in the case of mild steel, the bending effort of the first bend is proportional to the yield stress in tension of the material. It has been found by experiment that with the standard test piece ($\frac{3}{8}$ inch diameter) one-half of the bending effort in pounds-feet is nearly equal to the yield stress in tons per square inch. This rule is only approximate, but will give a fair idea of the strength of the material as expressed in the ordinary way. The number of bends is proportional to the ductility of the material, and experiment shows that this number is approximately proportional to the elongation multiplied by the reduction of area in a tensile test.

The area of the autographic diagram represents the energy required to break the test piece. The recording gear has been so proportioned that 1 square inch of this diagram is equivalent to 400 foot-pounds. The area in question can be obtained by means of a planimeter, but it can also be approximately arrived at by estimating the average bending effort, and multiplying by 1·6 times the number of bends. 1·6 times the number of bends must be taken, because, as already pointed out, the arc swept by the point of application of the bending effort (in pounds-feet) is 1·60 feet for each bend. This energy figure gives valuable information as to the quality of the material, and for machinery steel should not be less than 2,500 foot-pounds, but for the steel used in petrol engines and the like, a higher figure is desirable, say 3,500 to 4,000 foot-pounds.