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MR. A. E. OUTERBRIDGE, JR., President in the chair.

THE PRACTICAL ASPECT OF PRESENT COMMERCIAL METHODS OF TESTING IRON AND STEEL.

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Before entering on the discussion of the subject of the paper I have the honor to read to you this evening, I beg permission to state the reasons why the subject of testing iron and steel deserves general attention. Just now we appear to be in a transitory state concerning not only our social and political but our commercial and industrial organization. Among other things, we are learning somewhat painfully that the popular cry of our inexhaustible resources, which for years has been dinned into our ears, has been leading us into habits of extravagances which, to unlearn, will take another generation.

At the same time, it cannot be denied that the lavish use of our national resources has been instrumental in promoting our rapid development and in the attainment of our present commanding commercial and industrial position among the nations of the world.

The subject of small economies has become a favored study with engineers and managers of works at the present time, when financial success depends largely on the ingenuity displayed in the perfection of economic methods of production and management.

When it is found necessary for the manager of a furnace to expend \$40,000 for such improvements as will enable him to save 30 cents on the cost of producing a ton of pig iron; when the design of a heating furnace, promising the saving of 20 cents' worth of coal per ton of output, is anxiously studied by the manager; when the prices per pound of steel sold are calculated to the fourth decimal of a cent, and the saving of a hoop or two less on the barrels for shipping may represent all the profits on the investment in a year of depression, and when the increasing volume of available capital, with a consequent decrease of interest on the capital invested, compel the constructing engineer to provide for increased efficiency at a decreased cost, then we can readily perceive why the question of less quantity combined with better quality of the materials of construction has created a demand for means and methods to determine the most suitable qualities of these materials for a given purpose.

Thus the economic necessity of using the least permissible quantity of a material of approved quality has created an increasing demand for more or less elaborate systems of testing, inspecting and analyzing materials of construction. And since the results of the judicious application of the details of a system of testing involves questions of dollars and cents, success or failure, reputation or disgrace, of safety to life and limb, of freedom from anxiety and worry of various kinds, we may deem the consideration of the practical aspect of present methods of testing a question of economic value, a question of **dollars and cents** to the investor, to the director of a railroad, a

steamship line, or the stockholder of any concern, just as much as the profitable renting of a "skyscraper," of carrying passengers and freight, is a question of dollars and cents, the only difference being that the "skyscraper," the car or ship, carrying freight or passengers, is the end itself, while the testing of the materials used in building the "skyscraper," the car or ship, to make them useful as an interest-bearing investment, is a means to the end.

The measure of the value of a commodity is the proportional amount it takes to buy with it a given quantity of the necessities of life; or, conversely, how much we can buy of the necessities of life with a given amount of a commodity or its equivalent. If the commodity is worth much we get much, if it is worth little we get little. Similarly, the measure of the practical value of methods of testing iron and steel is the amount of knowledge we possess of the properties and qualities of these metals.

In other words, if we know much about the behavior of iron and steel under strain, our methods of testing will be the proper ones, and we will thereby obtain, or buy with that large amount of knowledge, if you please, a maximum of security, of safety, of reputation, of freedom from danger, anxiety and worry, of financial and social success for the investor and engineer. On the contrary, if our knowledge in this line of pursuit is inferior and defective, our methods of testing will be inferior and defective, and we can buy but a minimum of safety and success, with consequent loss through avoidable repairs, renewals, the use of more metal than is necessary, or inferior metal, and all this implies. Thus we perceive how proper methods of testing may become of high commercial value, a marketable commodity, as it were, of the knowledge we possess of the properties of iron and steel and the financially successful application of these properties.

Unfortunately, the effects of the work of proper or improper methods of testing are not so readily seen, demonstrable or calculable, as the correctness or usefulness of the structure can be measured, of which our work of testing is an essential part.

Let us examine for a moment what we are doing when we test a piece of iron or steel.

Testing will only then have a practical, that is, a commercially-economic value, if the method we use is in strict accord with the nature of the metal we test.

If the method is not in conformity with this essential requirement, which is the first principle in testing—that is to say, if by any method the metal which we test shows qualities different from those actually possessed by the metal we test—then our work of testing sinks to the level of an exhibition of the mechanical devices which we use for testing and of our skill in handling them.

All metals are viscous bodies, their viscosity being a matter of degree only and not of kind. Hence, the aim of testing must be to ascertain or measure the degree of viscosity possessed by the metal we test, and since it is the degree of viscosity which fits or unfits a metal to do a given work, it is obvious that methods of testing are of practical value in proportion to the degree of accuracy with which we ascertain the degree of viscosity of the metal we test and its natural behavior under strain.

Owing to the complexity of phenomena produced by the factors which tend to destroy a metallic structure, and to the inherent variableness of quality often found in the various members of a structure, or perchance in one of the members, and, owing to the want of opportunity by the engineer, which often prevents him, against his will, following up his observations to their sources by never-ending comparison with other similar metal, showing the same properties but varying qualities, there does at present not yet exist that uniformity of opinion concerning the properties and qualities of iron and steel, especially the latter, which is so desirable to produce the highest degree of economic value obtainable from a system of uniform methods of testing.

Of the various methods used at present to ascertain the physical qualities of iron and steel for structural purposes, the tensile test appears to be considered the most important and, therefore, the most widely used.

Although the value of the tensile test has been over-rated to a considerable extent, it is, nevertheless, an indispensable and most valuable guide in the realm of physical metallurgy. The engineer must have something tangible to base his calculations on, and this he can do only with the aid of the figures obtained in a tensile test.

Considering that a bending or nicking test of a whole bar shows its internal make-up as well and often better than the tensile test of a strip cut from that bar, it is within the limits of everyday experience to say that at present much time and money is spent for tensile testing of ordinary iron where a nicking test would answer the purpose and sometimes better.

The only advantage in such cases is that a tensile test is quite free from errors of judgment of the person making the test, while with a nicking test judgment and knowledge of methods of manufacture come into play if such a test is to be worth anything.

When making a tensile test, several different stages or phenomena attract our attention as the test proceeds.

In commercial testing these phenomena are defined as elastic limit, ultimate strength, per cent. of elongation, and per cent of contraction or reduction of area.

The elasticity of iron and steel is a complex function of the viscosity of the metal as a whole, the hardness of the individual crystal or fiber and the cohesive force by which these crystals or fibers are held together.

It is conceivable that the first strain applied brings the crystals or fibers into closer contact. If then the strain is released before sliding of the crystals and their deformation begins, they return or spring back to their original position, this action constituting the elasticity of the metals. If the strain is sufficient to produce sliding and deformation and the strain is released, the crystals will return or spring back only partly, while part of the deformation remains as permanent set. If now the strain continues without stopping, a point is reached where the viscosity of the metal comes into play.

At that point the metal begins to flow visibly, and flows so fast that, for a moment, it cannot hold up the weight or load

it had carried thus far. This point is indicated on the testing machine by the dropping of the scale-beam. If now the load is released there is a recoil as before, but it is very small, while the permanent set may be all the way from $\frac{3}{100}$ to $\frac{20}{100}$ of an inch.

After the drop of the beam the metal goes to destruction more or less rapidly.

Now it is this point when the beam drops which is called and assumed to be the elastic limit. Engineers and their inspectors use this drop of the beam in commercial testing almost exclusively, and of course the mills do not object as long as the consumer is satisfied.

In this illustration (*Fig. 1*) we can easily perceive the characteristic structural arrangement of a piece of steel.

FIG. 1.

There are variations in size and form of structure, of course, according to per cent. of chemical elements and mechanical treatment, but since the effects of stresses are probably the same on all kinds of structures, the structure in this piece of steel will do as well for an illustration as any other.

Considering that the hard crystals of steel are imbedded in a softer matrix, and that, generally speaking, the proportion of this matrix is greater in the softer grades of steel, which brings the hard crystals farther apart in soft steel than in hard steel, it does not seem to require a great deal of imagination to perceive that the first stresses applied will tend to close up the spaces between the crystals by bringing them closer together and compressing somewhat the softer matrix in which the crystals are imbedded or surrounded. On release of the

stress the compression on the matrix is removed, and if the stress has been below the limit of compressibility of the matrix, the crystals will return to their original positions without themselves suffering distortion.

The hardness and size and shape of the individual crystals, the proportion and plasticity of the matrix, with all the complexities of variables produced by work and heat in the steel or iron, probably are the causes which, by their action and reaction, produce that apparent irregularity observed in taking the elastic limit and to avoid which a short cut is taken across lots, and the first interval of stretch without increase of load is taken as the elastic limit, which is the point when the beam drops temporarily.

Since limit of elasticity means that point where, on release of the load, the material strained assumes its original form and

FIG. 2.

dimensions, it is obvious that a point where the permanent set measures from $\frac{3}{100}$ to $\frac{20}{100}$ of an inch cannot be the limit of elasticity.

Viscosity is active to change the form of the crystals. The cohesive force has yielded to the extraneous force and permitted the crystals to leave their original position and slide upon each other. The structure of the metal being thus in a disturbed and permanently distorted condition, it is self-deception to accept the drop of the beam as the limit of elasticity and as a basis of the engineers' calculations.

In this sketch (*Fig. 2*) the top line is the elastic limit or limit of proportionality. Each of the following lines represents 1,000 pounds of load applied while the test piece was under stress in the testing machine. The fifth line was made when the beam dropped, which means that in this case the so-called elastic limit is 5,000 pounds higher than the limit found with

the dividers. The changes taking place in the metal at the various stages of load and stretch are approximately illustrated in the diagram, *Fig. 3*.

Along the base line from *O* to *A* the stretch of the steel tested for each 1,000 pounds load is given in hundredths of an inch.

The actual stretch from load to load is magnified in the diagram for better illustration. The distances on the diagram between each succeeding load or vertical lines denotes that peculiar stage in the life of iron and steel where, after the elastic limit is passed, the metal stretches without increase of load. On the piece tested, the stretches between the point of elastic limit at 38,000 pounds and the drop of the beam at 42,000 pounds

FIG. 3.

were so small, not quite $\frac{1}{100}$ of an inch in 1,000 pounds, that they are not given singly on the diagram, but are included in the space between 38,000 and 42,000 pounds. If we now analyze the diagram, we find the elastic limit at 38,000 pounds. From there to 42,000 pounds is a total stretch, as already stated, of a hundredth of an inch. At 42,000 pounds the beam dropped and the test-piece stretched $\frac{6}{100}$ of an inch until the beam rose again at 43,000 pounds; at that load it dropped again, and there was an interval of stretch without increase of load of fully $\frac{3}{10}$ of an inch before the beam rose to mark a load of 44,000 pounds. For the next four intervals the stretch is uniformly $\frac{4}{100}$ of an inch each, after which it increases rapidly for each 1,000

pounds load, until fracture took place at 58,600 pounds. One of the objections made against the present method of taking the elastic limit by the drop of the beam, or yield point, is that the drop is often not well defined, or that there are more than one drop, thus misleading the operator, who then, in order to make some showing on paper, gives whatever drop seems to him the most pronounced, or, worse still, what appears to him as a drop of the beam, producing results which are mere guess-work, a delusion and a snare. In the diagram, for instance, the first drop, being only one-fifth the duration of the second drop, is easily missed, and thus the engineer is persuaded to base his calculations on an elastic limit, at which the metal, if loaded to that point in actual service, would stretch and set permanently $1 + 6 + 30 = \frac{37}{100}$ of an inch.

Another very striking example illustrating the foregoing is shown in the following results of tests of a bar of axle steel: The bar, after being forged to $1\frac{1}{8}$ inches in diameter, was cut into three equal lengths of 18 inches each. Test No. 1 was left as coming from the hammer. Test No. 2 was heated to bright cherry and buried in charcoal dust to cool slowly. Test No. 3 was heated to bright cherry and left to cool down with the furnace.

The elastic limit was taken with the dividers by the author while the man, operating the machine, and who is quite expert in that manner of work, noted the yield point.

COMPARATIVE RESULTS OF ELASTIC LIMIT (LIMIT OF PROPORTIONALITY) AND THE YIELD POINT AS OBTAINED BY THE DROP OF THE SCALE-BEAM.

FIG. IV. No.	ELASTIC LIMIT.		YIELD POINT.		TENSILE STRENGTH.	ELONGA- TION.
	Pounds per Square Inch.	Per Cent.	Pounds per Square Inch.	Per Cent.	Pounds per Square Inch.	Per Cent. in 8 Inches.
1	46,000	48·3	57,800	60·7	95,200	19·5
2	42,000	48·1	46,400	53·2	87,200	19
3	38,000	46·2	50,600	61·4	82,300	22

Analyses of these results show the elastic limit of No. 1 to be 48·3 per cent., and of Nos. 2 and 3, 48·1 and 46·2 per cent., respectively.

The elastic limit, as obtained by the drop of the beam or yield point, is 60.7 per cent. in No. 1, 53.2 per cent. in No. 2 and 61.4 per cent. in No. 3.

These figures appear all the more significant when we consider the well-known fact, liable of proof by any one who desires to do so, that annealing above 900° F. lowers the tensile strength, elastic limit and the yield point in proportion to the degree of heat applied.

In Bauschinger's "Mittheilungen," Heft XIII, page 26, it is said on this point:

"The effects of heating above that temperature (450° C.) and the subsequent slow or quick cooling consists in lowering the elastic limit and the yield point, the more so the higher the temperature was. However, the effects are greater on the former than on the latter."

Accordingly, we find the elastic limit in the annealed pieces Nos. 2 and 3 lower than No. 1. But, while the yield point of No. 2 is lower than of No. 1, it is higher in No. 3, although No. 3 is lower in tensile strength than No. 2 by 4,900 pounds. Thus we see that the method of taking the elastic limit with dividers, crude as it is, is still more reliable for revealing the true condition of the metal under test than the drop of the beam, which not only gives too high a value, but also gives results contrary to the accepted theories and practical experience.

If the elastic limit is a complex function of molecular movement of the individual crystals and a sliding upon each other of these crystals, then the smallest permanent set means a distorted structure of the metal from what it was originally, and if we apply from 3,000 to 12,000 pounds more load beyond the point where this distortion begins or up to the yield point, which is that point in iron and steel under stress where stretch momentarily increases faster than the load applied, then we clearly reach a point where a breaking up of the structure is near, or at least an entire change of structure takes place, due to the visible stretching of the metal. Hence, since a release of the load at the point of elastic limit means a complete restoration to its original condition of whatever distortion the

metal may have suffered at that point, while a continuation of the loading or stress beyond that point means not only a permanent but an increasing distortion in proportion to increase of load, and since at the point in testing where the beam drops temporarily because the metal is weakened momentarily to such an extent that it cannot carry the load, which means, if it means anything, an entire and radical change of structure at the yield point, a change in quality different from the quality the engineer had based his calculations on, therefore, the present method of testing, where the drop of the scale beam or yield point is assumed to be the limit of elasticity of iron and steel, is unscientific and unpractical, and a mistake, because at that point the structure or part of a structure has taken a considerable and visible permanent set, while what is meant by the elastic limit is a return to the original length, breadth or thickness of the metal on the release of the load. Beyond this point the engineer deals with new and unknown qualities of the metal.

Rather than to be satisfied with mere guesswork and self-deception, it would be better not to take the elastic limit at all.

Methods of manufacture have reached such a point of perfection in well-managed works that it is unnecessary to take the elastic limit of every test-piece. To take it occasionally with care, patience and accuracy is more rational than to be satisfied with what in many instances amounts to a mere guess. If the author has laid particular stress on this subject, it is because the limit of elasticity in iron and steel is the turning point from the known condition of the metal on which the engineer bases his calculations to the unknown condition of a changed structure about which the engineer knows nothing, knows nothing of its future behavior, and which change of structure we have reason to believe marks the beginning of the fatigue of a metal.

There is all the less excuse to be satisfied with a mere guess and a self-deception, since there are instruments in the market for determining the elastic limit, which, while they may not be perfect, are a great improvement over the data obtained by the drop of the beam. The ultimate strength is a reliable

measure of the power of a metal to resist stress, although the engineer does not consider his structure ever to be strained to the point of destruction. It has been proposed by some to stop testing at the elastic limit, by others to take the breaking load instead of the ultimate strength as the measure of value.

However, there are practical difficulties connected with the attempt to determine the breaking load accurately, and the proposition has been abandoned.

To accept the percentage of elongation in a given test section is a practical and reliable measure of the ductility of iron and steel. The elongation is the measure of the degree of plasticity which gives to a metal the power to yield under shock, to cushion the blow, as it were. Hence, the more plastic a metal the more it will stretch, and, therefore, this stretch, expressed in per cent. of elongation in a given section, is the measure of the degree of plasticity of the metal we test.

However, the flow of iron and steel under stress, due to these metals having the property of being viscous, is easily retarded by improper shape of test section, and the elongation, as a measure of the flow or plasticity of metals, will be of practical value only then if the test section gives free play to the viscous action of the metal under test. The 8-inch section, now generally used, fulfills this requirement better than any other section used in commercial testing, and, therefore, the present method of measuring elongation may be considered of practical value.

The same cannot be said of contraction or reduction of area as a measure of the commercial value of iron and steel. While contraction of area is valuable to the expert in the testing laboratory, in everyday commercial testing there is no time to study the various phenomena producing certain effects, but must have a direct exposition of the factors which tend to destroy a metallic structure. This contraction of area does not do.

In theory, contraction of area is supposed to represent the degree of plasticity of a metal by assuming that every particle of the metal under test is in prime condition to stretch and flow to its maximum capacity, until the extraneous force, trying

to tear the metal apart, is able to overcome the cohesive force with which the particles are held together. Wöhler, who has done so much to advance our theoretical knowledge of iron and steel, and who was the father of contraction as a measure of quality, based his earlier specifications on the above assumption by making tensile strength, plus per cent. of contraction of area, equal 100, 100 being the standard for quality, with a minimum allowance of 95. This assumption, however, presupposed an ideal metal, which we seldom get with the everyday production of masses of metal for commercial purposes.

Even with the exercise of proper skill and care there is no puddle ball or steel ingot having all its constituent elements distributed so uniformly as to leave no more of them in one place than in another, thus causing a difference in structure with a consequent difference in density, which in turn leads to an inequality of flow and power of resistance to stress. Hence, the particles cannot flow uniformly and uninterruptedly, even if they were not hindered in doing so by laminations, and, since rupture takes place at the weakest point, so likewise is contraction determined by local conditions principally and not by the condition of the whole mass of metal except there be ideal uniformity.

Moreover, unlike stretch, which becomes a measurable quantity at an early stage of the testing, contraction takes place chiefly between the period when the ultimate strength is reached to the point of fracture. It is, therefore, the last gasp, as it were, in the life of the metal tested, and a careful engineer does not expect his structure to break down. The difficulty of measuring the per cent. of contraction with anything approaching accuracy also tends to make this method of testing an unsatisfactory and unreliable one from a practical standpoint.

The fact that contraction is not uniformly proportional to strength, but shows an irregular, varying percentage, while elongation is more or less proportional to strength, also shows that reduction of area is an exponent of local rather than general conditions.

With special high-grade steel, like gun forgings and short

test pieces, it may be that reduction of area has some practical value, but such exception cannot be applied to the enormous masses of structural material of all kinds produced and used under the stress of everyday competition and manifold applications.

While elongation is the resultant of the stretch of every cross section of the area stretched, hence gives an average of the total variations of the whole section, reduction of area gives only the ability to contract at that portion of the section where the test piece breaks, which point includes only a few of the many cross sections into which the section may be divided.

Therefore, the larger the test section, other things being equal, the less representative a quality-measure reduction of area is, leaving out now all other considerations. These few test pieces explain this very well.

The practical value of the drop test as a quality measure is more and more appreciated by the engineer.

Iron and steel, when repeatedly subjected to dynamic stresses, shocks, blows or vibrations, is affected differently than when only static stresses are active to destroy a structure or part of a structure.

During a tensile test there is ample time for the quick-flowing molecules of structural iron and steel to adjust themselves to new conditions, induced by the stress operating to destroy the metal. Under the sudden shock of a drop test every individual particle is put on its own merits.

If the cohesion with which the particles are held together is inferior, there will be separation under but a few blows. If there is irregularity of structure, microscopic nests or veins of impurities or flaws, then such defects will act like wedges driven between the structure, and fracture will be from inward out.

To resist sudden shock successfully, the metal must be able to transmit the vibrations caused by the blow on the particles directly struck from particle to particle in the shortest possible time. If the tremor caused at the point of impact is not conveyed or conducted away quickly and distributed uniformly throughout the mass of metal, if the tremor is arrested by flaws,

laminations, segregations, irregularity of structure, etc., or if the metal is too brittle, does not cushion enough, as it were, then the metal will soon separate along the cleavage lines of the crystals and break under a few blows.

Hence the drop test as a measure of shock-resisting power is a very practical method of testing, provided the blows are heavy enough. If they are not heavy enough to bring out the possible defects at the first two or three blows, every succeeding blow heats the metal, causing a change of structure, thus minimizing certain defects that may exist in the metal. The function then of the drop or impact test of any kind is, first, to determine the presence of such defects which mechanically separate the particles of the metal, or, in other words, impair their intimate contact and adhesion, and, second, to determine the ability of the metal, other things being equal, to absorb, as it were, to convey and distribute over every—even the smallest—cross section of the metal the vibrations produced on its surface by shocks, in order to prevent the overstraining, and hence fatiguing, of any cross section of the metal at the expense of its neighbors, thus producing early fracture.

The nicking and bending tests are extremely valuable, either for themselves or as auxiliaries to the tensile test.

Nicking a piece of steel or iron on one side and breaking it quickly will show several things. If iron, a nicking test will show whether it is clean or dirty, short fibered or long fibered, dry or juicy, coarse crystalline, due to cold shortness, or that fine, mushy, silvery granulation so characteristic of burnt iron. In steel the nicking will show laminations, shortness and, to a certain extent, want of uniformity of heating of the material in the mill, if there are many pieces of the same kind of metal to be tested..

The bending test is quite a reliable measure of ductility, more so for middling hard grades of steel, from boiler grade up, than for the softer kinds. Steel flows so easily under even moderate pressures that a dead-soft piece of steel must be very bad indeed if it will not stand bending double without signs of distress. What makes the bending test valuable with middling hard steel is the severe strain the bending imposes on the

cohesive power which holds the particles of the steel together.

Generally speaking, steel consists of two distinct bodies, a harder body, forming the crystalline portion, imbedded in a softer mass. We have reason to believe that the hard body predominates in the harder grades of steel, while it forms but a small percentage of the total mass in the soft grades. It is the soft body chiefly which imparts ductility to steel.

Now it is clear that, in order to produce maximum resistance to rupture, the union between these two bodies must be at its best in order to resist the severe strain on the convex surface of a bent piece of steel.

For this reason, if the convex surface has a velvety appearance without exhibiting the least skin cracks even, we have a right to conclude that a piece of steel thus tested is of very good quality, always provided that the bend is sufficiently large to strain the metal to its utmost. For these reasons also bending tests on square or cornered bars are more severe than on round ones. The above points are also applicable to iron with certain modifications.

Under certain conditions the nicking and bending test may become much more valuable and reliable as a quality measure than the tensile test.

The elongation, measured around the convex surface of a bent piece of steel, is often found to be equal, or a little more, to the elongation in a 2-inch section of a tensile test.

The nick-bending test is still more effective than the nicking test alone or the bending test alone. A piece of structural iron or steel must be very good indeed to suffer bending upon itself after having been nicked, which is meant by a nick-bending test.

Especially on steel is this a very severe test, because, if the crystals of steel are once separated anywhere in the mass, this separation is readily continued along the cleavage faces where the crystals adhere to each other by their sides. To be able, therefore, to bend a nicked piece of steel upon itself means superior cohesion of the particles, which, if the strength is sufficient, means an excellent material for constructive purposes.

The quenching test as a measure of quality and practical

utility may be considered of doubtful value. So many variables enter into the successful performance of this test that it is very easy to produce such conditions as will nullify the object we intend to accomplish.

A successful quenching test requires the uniformly carrying out of the details to be observed more accurately than any other test, because the heat employed will produce different effects from those we expect to get if that degree of heat is not in conformity with the point at which the chemical elements change in the steel.

The investigations of Osmond, Brinell, Charpy, Arnold, Hadfield, Saveur, Howe and others point to the conclusion that the changes in properties in steel due to heat treatment take final and definite shape within well-defined and somewhat-narrow limits. Below these limits complete change of elements does not take place.

In ordinary annealing, experienced judgment is a sufficiently close guide to produce the effects we desire. In the process of tempering tools we are guided by the variously-colored films of oxide forming on the steel.

In the specifications for quenching tests we usually find the empirical statement of "cherry heat," or the still-less intelligent expression "blood heat."

These terms are applied to all grades of structural steel, notwithstanding the fact that the effects we intend to produce by these degrees of heat are not alike on all grades of steel. In other words, since variation in the percentage of chemical elements in steel require varying degrees of heat to produce a desired change, the now uniformly applied so-called "cherry" or "blood heat" will produce varying effects on the piece quenched without our knowing what these effects really are.

Thus the operation of quenching as usually performed is a crude guesswork, a hit or miss performance, unjust to the manufacturer and misleading to the engineer.

To do justice with a quenching test to ourselves and others we ought to specify the chemical composition the material to be quenched ought to have, the degree of temperature at which that particular change of chemical elements takes place which

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is to produce the effect we expect and desire, and the degree of temperature of the quenching fluid at which the change of elements in the steel becomes fixed.

Brief and incomplete as the foregoing explanation is, it will probably indicate that the performing of a proper and reliable quenching test requires knowledge of the carbon contents of the steel to begin with and the measuring, by means of a pyrometer, the degree of heat of the steel just as much as we measure the temperature of the quenching fluid. Only with the co-operation of these three factors can we claim practical usefulness for the quenching test.

Routine transverse tests are principally made on cast iron and other hard material.

On account of the absence of the restraining influence of grips or holders, every particle of the metal in a transverse test piece is free to act, and, therefore, such a test is a reliable measure of ductility and homogeneity.

Especially for cast iron this test is preferable to a tensile test of that metal. The ductility of cast iron is very small, and what little viscosity there is is overbalanced by the rigidity of the metal to such an extent that there is no measurable flow, and, therefore, fracture takes place with the beginning of flow, and no measurable elongation is obtained in a tensile test of cast iron. What little ductility there is is hindered from becoming manifest by the restraining influence of grips and the eccentricity of the pull of the testing machine.

Whatever eccentricity there is in a testing machine, however small, in the test of a cast-iron test piece it is sufficient to snap off the piece sideways before the small amount of ductility there is has time to assert itself. This is probably the reason that, while we get no elongation in a tensile test of cast iron, the same iron tested transversely will give from $\frac{5}{100}$ to $\frac{1}{10}$ of an inch deflection, showing that, while our method is in conformity with the nature of the metal under test, the other method is not.

Only when there is a long-continued series of cast-iron tensile tests made under the same conditions with the same mixture is a tensile test of cast iron of approximate value, because

then the error of eccentricity practically becomes inoperative as to result.

In the foregoing the author has not taken into consideration the possible influences of internal strains in cast iron, and of which Mr. A. E. Outerbridge has made so successful a study.

Crushing, shearing, punching and torsion tests are special tests, not used frequently as commercial tests, and, therefore, are not discussed at present.

Hammer tests are seldom made, although they are very valuable.

Drifting tests are used in bridge material, and are very effective tests for ascertaining ductility and homogeneity.

Fatigue tests will not come into general use as commercial tests because of the length of time necessary to make such tests.

At present we find specifications for fatigue test of stay-bolt iron in satisfactory operation. The underlying idea of this method of testing is to imitate the effects of the movements of a locomotive boiler, or rather its fire-box, caused by contraction and expansion on the stay-bolts of a boiler. While such imitation of natural causes can only be approximate, there is reason, nevertheless, to believe that such commercial-fatigue tests will prove of considerable practical value.

While the microscopic examination of iron and steel has not yet attained to the dignity of a commercial method of testing, yet the growing use of the microscope in mills and testing rooms gives promise that ere long this valuable auxiliary to the physical test and chemical analysis will be accorded its proper place as a standard method of testing, and thus justify the expectations of the pioneers of this valuable work, Sorby, in England; Martens, in Germany, and F. L. Garrison and C. Roepper, in this country.

The study of the microstructure of steel has not yet evolved fixed laws by which the practical value of a given structure of steel may be called standard.

But that much we know, that the microscope is to lead to a solution of some metallurgical problems, especially the effect of heat treatment, with all its apparent changes of structure and physical behavior.

From what little work the author has seen done with the microscope by others and has done himself, he cannot share the enthusiasm of those who claim that the microscope will supersede the chemical laboratory in its usefulness.

Summarizing our very brief inquiry into the practical aspect of present commercial methods of testing iron and steel, we find that in some of these methods we are following the laws of nature, while in others we are trying to squeeze the properties of these valuable metals into the straight jacket of conventional rules and methods with consequent unreliability of results.

Much as we know about the properties and qualities of iron and steel, there is still more to be learned.

However, there is a growing sentiment and desire in many quarters for information and thorough investigation, and the author sincerely hopes for the hearty co-operation of the Franklin Institute and the International Association for the Unification of Methods of Testing Materials of Construction, as well as the manufacturers and engineers of the country, to bring about that understanding of the properties and qualities of iron and steel and uniformity of methods of testing these metals for the mutual benefit of our commerce and our industries and the welfare and prosperity of our country and all countries, for science has no nationality.

DISCUSSION.

THE PRESIDENT OF THE SECTION:—I am sure that I express the unanimous sentiment of the members of the Mining and Metallurgical Section of the Franklin Institute when I say that we are much indebted to Mr. Kreuzpointner for his instructive and interesting contribution to our rapidly-growing literature upon the important subject of testing iron and steel.

The able addresses on this and cognate topics, which have followed each other month by month since the formation of this section a little more than a year ago, have proved that its creation was timely, and I am convinced that its future is bright with promise of still further expansion and usefulness.

Mr. Kreuzpointner has skilfully avoided falling into an error common to experts in discussing their specialties, of contracting their vision within the range of a very limited horizon; he has taken a broad view, and his introductory words recall to my mind some remarks of a French engineer, who visited this country about a year ago, and whose shrewd observations on the economics of American industries were extensively quoted in technical periodicals at home and abroad; he attributed the phenomenal advancement of this country in all mechanical industries mainly to the close attention given to technical details.

Mr. Kreuzpointner has unflinchingly pointed out facts in his discussion of the present methods of testing iron and steel, which may, perhaps, appear discouraging but knowledge of our shortcomings is really the first step towards advancement, and I think you will agree that there are a number of so-called "mysteries" waiting to be cleared up in connection with this subject. Sir Benjamin Baker marshalled before the engineering world many unexplained phenomena of metals in his presidential address at the "Institution of Civil Engineers," in 1895. If I correctly remember the substance of his remarks, he said something like this: "Who can tell what mysterious changes are occurring day by day, week by week, year by year, in metals, such, for instance, as hardened steel projectiles, leading sometimes to their violent disruption; who can explain that great mystery of the bridge links from the old Hammersmith Bridge made of the toughest iron, which, after successfully withstanding sixty years of hard usage, snapped in two by the score while being shipped to Edinburgh, although, when the halves of the broken links were subsequently thrown down from the top of the Forth Bridge on to the rocks 300 feet below, they bent like cockscrews, without fracture?"

Many years ago, Sir William Thomson (Lord Kelvin) showed that iron rods or wires, which were kept in torsional oscillation during the week, behaved very differently after a rest over Sunday, and these observations have been confirmed and elaborated by others. Sir Benjamin Baker stated that it has been recently shown that owing to the molecular settlement which occurs during rest in an overstrained bar,

the modulus of elasticity will rise 10 per cent. after three weeks' holiday.

The present methods of testing cast iron, and of determining therefrom the strength of castings made of this metal, are ludicrously or rather lamentably faulty, and they will, no doubt, so continue to be until engineers learn to appreciate more clearly the enormous influence that the rate of cooling exerts upon its physical properties. In this respect cast iron differs radically from cast steel or from other metals. The strength of cast iron test bars is not a safe guide upon which to predicate the strength of iron castings unless all of the relative conditions are known and taken into consideration. For instance, if you will cast from one ladle of iron two test bars, preferably in the same mold, one let us say, of 4 inch, the other of 1 inch section, turn them to the same dimensions and pull them upon a testing machine, you will probably find—I may say I am sure of it—that one of the test pieces will be *at least 50 per cent. stronger than the other!* I know that such a startling statement may seem incredible to any one not familiar with the facts, but I speak thus definitely and positively from experience.

The subject of Mr. Kreuzpointner's paper is open for discussion, and I am glad to recognize in the audience several gentlemen who are themselves experts in such work. I hope that they will express their views, and I will call upon Mr. Backstrom who, I know, has had years of experience in testing iron and steel, using the well-known "Emery" testing machine for that purpose, to say a few words upon the subject.

MR. G. L. BACKSTROM:—I do not agree with the author and his statement that cast iron has not perceptible elongation.

In numerous tests I have had occasion to make myself I have found elongations, ranging from .15 to .45 of 1 per cent., in cupola iron, and while specimen was under strain, and I think that the elongation of a cast-iron specimen will enable one to form a pretty good idea of the quality of the material being tested.

As to the difficulty of making reliable tests on cast iron, I lay that wholly to defective apparatus and carelessness of

operator. Proper preparation of specimen and a machine in perfect alignment will overcome these difficulties.

MR. JAMES S. WHITNEY:—Referring to tests of cast iron, I have in mind the “thermal test” now enforced by the Pennsylvania Railroad to try the quality of chilled iron car wheels. It may be remembered that this test consists in subjecting the cast wheel, when cold after annealing, to the sudden heat of a ring of molten metal poured around the chilled rim or “tread.” This is done to roughly simulate the action of brakes, which on long down-grades is frequently sufficient to crack the gray iron plate of the wheel partially away from the tread by the expansion of the latter due to the heat generated.

The metal may be such as to stand the “drop test” and yet fail in the “thermal test.” In view of the considerable differences in both the temperature and rate of cooling of molten cast iron of different chemical proportions, it would appear reasonable that some limits should be imposed as to the kind of molten iron to be used for this ring, and the pouring temperature. A close-grained metal used for brake shoes not only may come from cupola much hotter than wheeliron, but also loses its heat more rapidly at first, as our tests with an optical pyrometer have shown.

MR. KREUZPOINTNER made answer that the thermal test being a foundry test for wheels was not in his department, but that he believed it to be a good practical test, and that the requirement that the wheel should not break into two or more pieces within two minutes after pouring the ring, assured to the Pennsylvania Railroad a safer quality in the cast of wheels represented by the test wheel than if the drop test alone was relied upon.

At the wheel foundry of the Pennsylvania Railroad at Altoona molten wheel iron from the regular run for wheels is used for this test, and the moulders are quite expert in judging the temperature of the iron before pouring the wheels, being docked for loss of wheels poured too hot or too cold. Hence there is every probability that the iron used for making the thermal test is neither too hot nor too cold.

As to Mr. Backstrom's remark about there being some stretch in a tensile test of cast iron, I beg to say that I am

well aware of this fact. However, all my remarks made here to-night apply only to commercial methods of testing, and in the everyday practice of commercial testing it is simply out of question to use continually sufficient time and such scientific methods and elaborate instruments as are necessary to determine the elongation of a tensile test-piece of cast iron. Since the easily-measured deflection of a transverse test-piece of cast iron answers all the purposes of commercial testing, the latter method of testing cast iron appears to be more reliable, and therefore preferable whenever more or less rapid work becomes a necessity.

MR. ASA W. WHITNEY:—In the case of the drop test there appears to be a relation between the quality of resilience, as shown by the slow deflection of a transverse test bar, and the quality of metal which longest endures the shock of the drop test on a casting in form of a chilled wheel. Of course, this relation is complicated by the capacity of the metal for chill. But for same depth and quality of chill as shown in the wheel or chill test, the resilience $\left(= \frac{\text{stress} \times \text{deflection}}{2 \times \text{weight of bar}} \right)$ of 4" area hexagon bar indicates quite fairly the quality or relative number of blows under the drop test when in form of a chilled wheel. Only by very close regulation of cupola charges for many years on a strictly chemical basis has it been possible to observe the relations of this kind in the narrow ranges of figures indicating practically equivalent chemical compositions. Further study may indicate a similar physical relation to the thermal test besides limiting chemical composition in certain directions, though thorough annealing is a very important point.