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THE NOTCHED BAR IMPACT TEST

The object of all tests of materials is to determine whether the material will satisfactorily withstand the stresses to which it is subjected on service. With this object in view it is customary to apply to representative samples certain tests of which the principal ones are the tensile and the bend tests. The tensile test gives a measure of the " strength " of the material as indicated by the yield point and the ultimate tensile strength and it further indicates its ductility as measured by the percentage elongation and the reduction of area. Adequate strength is necessary to ensure that the part is not deformed or fractured by the forces to which it is normally subjected on service while a good degree of ductility is looked upon as an insurance against occasional abnormal stresses, deformation taking place rather than fracture. It is found, however, that materials even when actually possessing a quite adequate degree of strength and ductility, sometimes fail in a manner which appears to indicate almost complete absence of these properties, the fracture being crystalline and without deformation. In such cases the material is said to be " brittle " and it has been found that this property of brittleness is best indicated by a machine which breaks a notched specimen and measures the work absorbed in so doing. Such a machine is the Izod notched bar impact testing machine and its value as an indicator of this property of brittleness is shown by the following examples.

A crane hook which failed under a very low load, was found to have a tensile strength of 26 tons per sq. inch with an elongation of 40 per cent. and a reduction of area of 70 per cent., yet the Izod impact figure was as low as 4 ft. lbs. The hook failed because it had been annealed and allowed to cool slowly, as much lifting tackle is, very much to its detriment.

A piece of the hook reheated to 950° C. and allowed to cool freely in air showed similar results under tensile test, but its Izod value had risen to 86 ft. lbs.

In another case, an aeroplane crank shaft fell accidentally out of the lifting tackle and broke. No clue to the mishap was given by the usual tensile test results which were as good as those obtained from an identical crank shaft which could not be broken under a steam hammer, Izod tests, however, immediately revealed the difference in the materials, the full test results being as follows :—

——	Brittle Crankshaft.	Tough Crankshaft.
Yield point (tons/in.^{2})	45·0	45·6
Maximum Stress (tons/in.^{2})	53·7	52·4
Elongation (per cent.)	21·0	21·0
Reduction of area (per cent.)	55·8	59·3
Izod test (ft. lbs.)	2 and 3	76 and 77

The principal machines used for carrying out the notched bar impact tests are the Izod and Charpy, and both work on the same principle. A heavy weight is fixed to the end of a long lever pivoted at its other end and swings as a pendulum. At a position at the bottom of the pendulum stroke a vice is fitted in which the specimen is gripped with the notch just showing above the jaws. The weight is released from a certain fixed height, swings down and delivers a blow to the specimen, breaking or severely deforming it, and then swings up the other side, an indicator being fitted which shows the height which the pendulum attains.

The Izod machine is shown in Fig. 1.

Neglecting friction, the work required to break or deform the specimen is the weight of the pendulum multiplied by the difference between its height at the beginning and end of the stroke, and may be measured in foot pounds.

In the Izod test a Standard V-shaped notch is used. In the Charpy test a keyhole shaped notch is used, and the machine is on a larger scale. Frémont and Amsler Machines which work on similar principles are also used.

The depth and shape of the notch and the size of the specimen all have their influence on the test results and of course to obtain comparative figures similar machines and standard specimens must be used.

The notched bar test is essentially a practical one, designed to reproduce a condition which is very common on service, where a machine part in which a concentration of stress occurs due to a change in section is subjected to shock. The work required to break the specimen is made up of two parts, firstly that necessary to cause the deformation to take place before a crack is started, and secondly the work required to propagate the crack through the material. The test is a combination of a true brittleness test (*i.e.*, to propagate the crack) and a " bend " test.

It is an unfortunate feature of the impact test that the scale of the test has a marked effect upon the results. The work required to " deform " a specimen, within or outside the elastic limit conforms to the usual laws of similarity of structures, but the work required to propagate a crack is relatively less as the size of the specimen increases. It follows therefore that the test cannot be used to discriminate between different materials, as the scale effect is unknown. The value of the test lies in the detection of undue brittleness which may be due either to improper heat treatment or segregation of inclusions, and it is a very valuable aid to the adjustment of a proper heat treatment, the effect of heat treatment on impact strength being very great.

It may be noted that the difference in structure between a material of high impact strength and a similar material of very low impact strength is not always observable under the microscope.

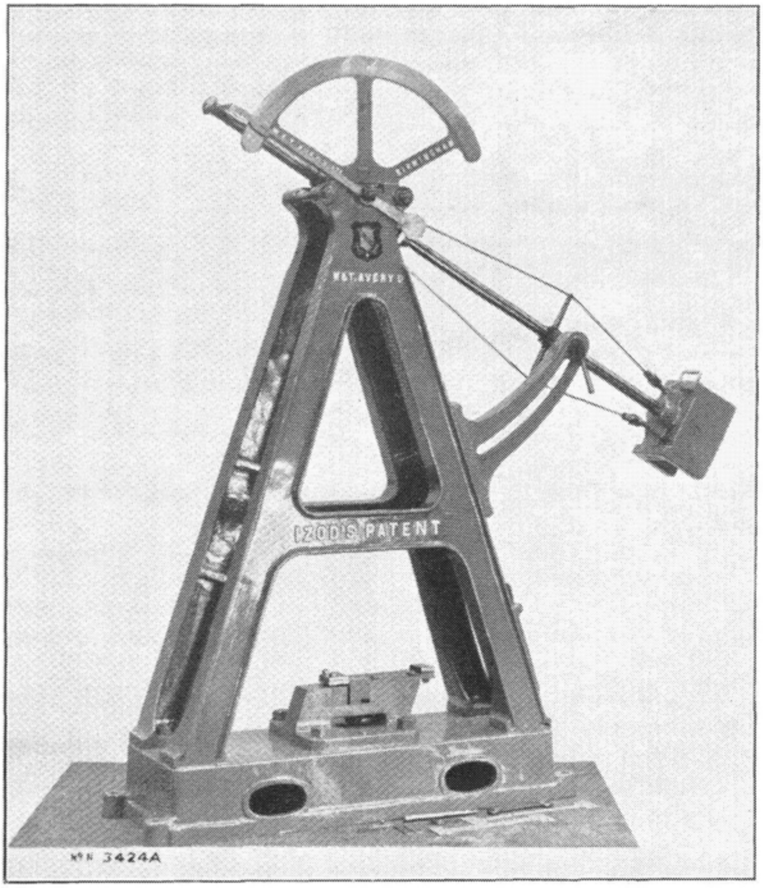

FIG. 1.

Enough has been said to emphasize the point that impact test results have no relation to yield point, ultimate tensile strength, elongation or reduction of area or other physical properties indicated by any other test.

The depth of the notch has an important bearing on the test results, since, particularly in tough materials, if the notch is not sufficiently deep, a shearing fracture may be obtained instead of the typical transverse crystalline fracture and this alters the character of the test and vitiates the results obtained. Without a notch at all, tough and notch brittle steels may give similar test results.

The sharper the radius at the root of the notch, the less energy is required to break the specimen, as the stress concentration is greater and the crack starts earlier, and since the test becomes nearer a true brittleness test, a greater contrast between tough and brittle materials is obtained.

The errors introduced by inaccuracies in the manufacture of the test pieces and the variability of the results obtained increase as the notch is made sharper, and this sets a limit to the sharpness which can be adopted. The standard root radius adopted for the Izod test is 0·25 millimetres.

It is important that the milling cutter used to produce the notch should be maintained at standard dimensions and not allowed to wear and produce a notch of larger radius than the standard which will result in Izod test values being "high." A formula given by Dr. Unwin to enable a comparison to be made between Izod test figures for specimens made of the same material but of different sectional area is $W = Ca^n$ where W = work done, C and n are constants and a = area of cross section of bar. The value of n for carbon steels varies between 1·16 and 1·45 increasing as the carbon content increases, but great caution should be observed in using this formula which may not be generally applicable.

In general the velocity with which the blow is struck has little effect on the Izod value in the case of ductile materials, but the energy absorbed tends to increase with the speed of the test. In the case of harder materials the energy absorbed either falls continuously as speed of test increases, or rises to a maximum at some intermediate speed and falls thereafter until the maximum test speed is attained.

In the case of these hard materials, as the speed of the test increases, the cracking takes place earlier and the crack is propagated with greater rapidity, that is to say, the materials are "impact brittle" to a greater or less degree.

The temperature of the test piece has a marked effect on the results of the test. In any given steel there is a small critical range of temperature below which the Izod value is low and the fracture is brittle and above which the Izod value is high and the fracture tough. Within this critical range it is doubtful which type of fracture will occur and in general either high or low Izod values are obtained though in some rare cases intermediate values have been obtained. The limits of the critical range for wrought iron and mild steels is from – 80° C. to 100° C., though in any individual specimen the actual range is of course very much smaller than this.

In individual cases, the critical range covers a few degrees on the temperature scale, but it is often referred to for convenience as the "temperature of inflexion."

The temperature of inflexion is affected by the condition of the material, and in hot rolled carbon steels it is sometimes about the atmospheric temperature, hence when Izod testing such material a few degrees of temperature difference in the test shop may decide whether the result will be a shearing fracture and high Izod Impact figure or a transverse crystalline fracture and comparatively low Izod value.

Cold work increases the temperature of inflexion progressively, also if high tensile stresses are applied to wrought iron and mild steels whilst they are hot and they are then cooled and the stress relieved, it is found that the temperature of inflexion is raised.

This variation of the Izod test values with temperature affords an explanation of the failures of machine parts which sometimes take place in very cold weather, and the rise of temperature of inflexion when material is heated under stress provides an explanation of the phenomena of impact brittleness often observed in mild steel steam pipe bolts after service, although in the latter case, it is not the full story.

Mild steel frequently suffers from age embrittlement ; if the material is subjected first to a stress which is locally high enough to cause it to yield, and then to a temperature of about 400° F. for a short time or a lower temperature for a longer time, it frequently becomes notch brittle, its impact value falling to as low as 2 or 3 ft. lbs. at atmospheric temperature, although it is not so brittle at the high temperature.

With average and brittle materials the type of fracture obtained is a transverse crystalline one as shown in Fig. 2.

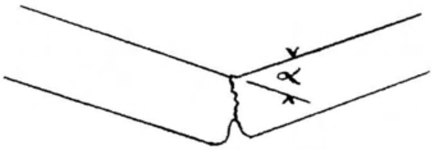

FIG. 2.

The surface of fracture is approximately a plane inclined at an angle $(90^\circ—\alpha/_2)$ to the axis of the specimen. The angle α is a measure of the deformation of the specimen before cracking and is somewhat analogous to the elongation in a tensile test and gives

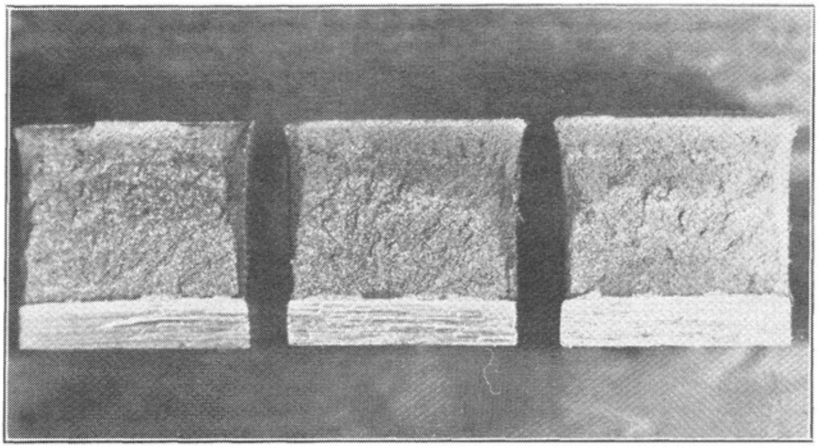

FIG. 3.

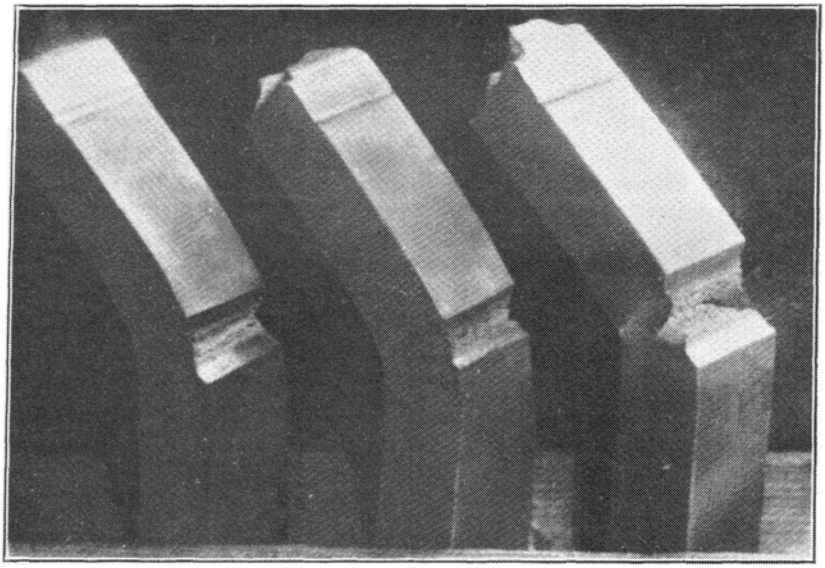

FIG. 4.

most useful complementary information as to the nature of the material.

All metals have a crystalline structure, but if distortion and elongation of the crystals take place before the metal is fractured, the fracture has an appearance which is called " fibrous " whilst if fracture takes place without appreciable distortion of the crystals the fracture is termed crystalline.

Failure by shear always gives a " fibrous " appearance to the fracture.

Under the impact test, very tough materials fail with a so-called fibrous fracture, whilst at the sides of the test piece are " horns " which indicate failure by shear. Figs. 3 and 4 show brittle and tough test pieces respectively after test.

The angle α in brittle materials is negligible, but may be considerable in the case of tough materials.

A material may become embrittled through use or age, and thus the nature of its fracture will be altered, but the structure of the material (which is always crystalline) will not alter, except that under certain circumstances the crystals may grow in size.

Sir Robert Hadfield gives the following figures for impact test results which should be obtained with correctly heat treated specimens of different compositions, although it must be remembered that individual tests often vary considerably from the average.

The results quoted are for test pieces cut longitudinally, *i.e.*, parallel to the axis of the original ingot ; in general it will be found that test pieces cut transversely will have a lower Izod figure in some cases as low as one-fifth or even one-tenth of the figure given. The explanation of this is that the original ingot has a number of globular non-metallic inclusions or impurities in it ; during the forging, rolling or drawing operations required to produce the finished article, the deformation of the metal draws out these inclusions into long very thin " pencils " or lines, running parallel to the original axis of the ingot. If these numerous lines of inclusions run transversely across the specimen to be tested, they very considerably weaken its resistance to impact ; similarly in tensile or bend tests transverse specimens show lower ductility although the tensile strength is not much affected.

Comparison between the Izod values of longitudinal and transverse specimens gives a good indication of the amount and distribution of slag inclusions in the material.

Austenitic steels in general show high Izod values, about 80 or 90 ft. lbs. indicating that the material is tough.

A fully hardened steel will have a very low Izod value, but if the material is subsequently tempered the impact value will increase with the tempering temperature and will eventually reach a figure higher than that of the material in a normalised or annealed condition.

Brinell Ball Hardness No.	Approx. Scleroscope Hardness No.	Yield Point Tons sq. in.	U.T.S. Tons sq. in.	Average Izod Ft. lbs.	Based on	Examples.
100	19	13	26	80 to 55	Carbon Steel	Forged mild and medium hard steel.
125	23	17	31			
150	27	21	36			
175	30	26	41			
200	34	32	46			
225	38	38	51	55 to 28	Alloy Steel *e.g.*, Ni. Cr.	50 to 60 ton alloy steel for bars, forgings, &c.
250	42	44	56			
275	46	50	60			
300	50	55	64			
325	54	61	69	28 to 12	Steel quenched and tempered	60 to 70 ton alloy steel for crankshaft, 70 to 80 ton alloy steel for connecting rod forgings.
350	57	67	74			
375	61	73	79			
400	64	79	86			
425	68	85	92	12 to 8		100-ton alloy steel for gears.
450	71	92	100			
475	75	99	107			
500	78	105	115			
525	80	111	122	8 to 4		120-ton alloy steel.
550	84	118	130			
575	86	125	137			
600	89	132	145			
625	92	139	152	Below 3	Carbon or alloy steel	Hardened material of various types.
650	95	146	160			
675	99	153	169			
700	101	160	178			
725	Not definitely determined				Carbon or alloy steel	
750						
775						
800						

In the case of tempered steels, the rapidity of quenching is greater for small articles than for large ones, and consequently the hardness obtained at any particular quenching temperature, and the Izod value of a specimen of the material will depend on the size of the original forging.

High sulphur or phosphorus content will produce brittle steels and such brittleness cannot be cured by any treatment.

The form of the British Standard notch bar test piece (B.E.S.A. Spec. 131) is shown in Fig. 5. Three notches are made so that the specimen may be struck three times and the mean of the three readings taken.

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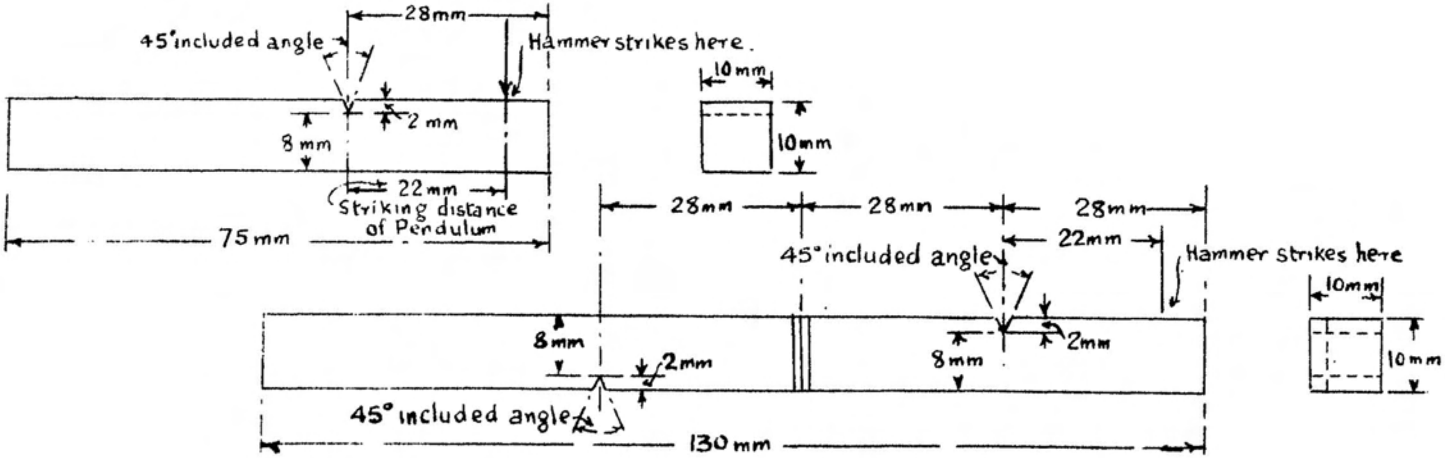

FIGURE 5.