10

Impact Strength

10.1 General Considerations

10.1.1 Introduction

The decidedly *ad hoc* field of impact testing has received considerable attention in official standards, materials data sheets and the literature because the impact properties of plastics materials are directly related to the overall toughness of the material. The concept of 'toughness' is one that most people can readily appreciate and a broadly accepted definition is the work done in breaking a test piece or object.

The one advantage impact tests offer is a ready measure of the actual energy required to break the test piece. This information can of course be calculated from stress-strain diagrams in, say, tensile (Chapter 6) or flexural (Chapter 9) tests. In the past this could only be achieved through some considerable effort, but with the widespread use of computers to control testing and to process test data, it has become as easy to derive work energy from these tests as from the impact test. While such data are quite useful for describing the behaviour of plane-faced objects, the area under a conventional tensile or bending test curve is of limited value because in practice one is frequently interested in toughness under conditions of rapid deformation. There is, however, much technical complexity in carrying out tensile tests and other modes of deformation at high speed. Thus, the concept of impact resistance or 'strength' and the introduction of impact or shock resistance tests, and its assessment follow naturally from these concerns.

It should be remembered, however, that the result of an impact test is basically no more than one point on the general curve of studying strength properties as a function of speed of testing. There are a large number of standardised impact tests, which is in stark contrast to the scarcely standardised subject of high-speed mechanical testing using tensile, flexural, compressive or shear geometries.

10.1.2 Modes of Failure

Energy is required both to create a crack and to allow this crack to be propagated through the material. The energy to initiate a crack is called the crack initiation energy. If the available energy in the system undergoing impact exceeds the crack initiation energy, the crack will continue to propagate and complete failure will occur if the system has sufficient energy to also exceed the crack propagation energy. Thus, both crack initiation and crack propagation contribute to the measured impact energy. Vincent [1] has identified four basic types of failure that are encountered under impact and the result of an impact test may result in different types of failure. It is important in interpreting the results of a test that test pieces exhibiting different kinds of failure are not pooled together.

- Brittle fracture is where the part fractures extensively without yielding and typically has sharp 'glassy' edges. General-purpose PS typically exhibits this type of failure under impact conditions.

- Ductile failure is where there is a definite yielding of material, often indicated by stress whitening, along with cracking. Polyolefins are generally considered to be ductile materials.

- Yielding is where the part exhibits obvious and permanent deformation and stress whitening but no cracking takes place.

- Slight cracking is where the part shows evidence of some cracking and yielding but without losing its shape or integrity.

The distinction between the four types of failures is not always very clear and some overlapping is quite possible. For particular standardised test geometries, defined modes of failure may be given and test pieces must be assigned to one of these categories. For Charpy and Izod tests, for example, the following definitions along with their letter abbreviations need to be adopted:

C complete break; a break in which the specimen separates into two or more pieces.

H hinge break; an incomplete break such that both parts of the specimen are held together only by a thin peripheral layer in the form of a hinge having no residual stiffness.

P partial break; an incomplete break that does not meet the definition for a hinge break.

NB non-break; in the case where there is no break, and the specimen is only bent, possibly combined with stress whitening.

10.1.3 Factors Affecting the Impact Strength

10.1.3.1 Rate of Loading

Because plastic materials are viscoelastic, the speed at which the test piece or part is struck has a significant effect on the behaviour of the polymer under impact loading. At low rates of impact, relatively stiff materials can still have good impact strength, but at high enough rates of impact, even rubbery materials will exhibit brittle failure. All polymer materials seem to have a critical velocity above which they behave as glassy, brittle materials. This has important consequences for designing with plastics. If in a particular application the product will ‘see’ impact speeds of 50 m/s then it is dangerous to base a material selection on normal impact tests like Charpy or Falling Weight because the impact velocities are an order of magnitude lower and a material that behaves in a ductile manner at these speeds may become brittle at the application speed. After using these tests for screening potentially useful candidate materials a more specialised and probably *ad hoc* test, perhaps involving firing a projectile at the materials, will be needed. Otterson and co-workers [2] report the effect of testing speed on blends of Nylon 6 and acrylonitrile-butadiene-styrene (ABS) for crack growth resistance while Douglas and Leevers [3] consider the effect of test speed and geometry on pipe grade materials using a recently developed dynamic and fracture model. The effect of deformation rate on fracture toughness values has been considered by Pinardag and co-workers [4].

10.1.3.2 Temperature

Again, the viscoelastic nature of plastics makes the effect of temperature much more significant than it is for materials like ceramics and metals. Decreasing the temperature tends to promote the onset of brittle failure. It is therefore important to take account of the temperature range that the article might see in service and to conduct impact tests over that temperature range as far as practically possible. Note that increasing temperature has the opposite effect of increasing speed and so there is not a single temperature at which brittleness occurs, but a locus of temperature/speed values where the transition from ductile to brittle behaviour takes place. Every polymer has its own characteristic locus. Weier and Hemenway [5] consider a number of factors affecting the process of energy absorption during impact testing with temperature being one of these factors while Takeda and co-workers [6] focus on the effect of temperature and water content on Nylon 6 composites.

10.1.3.3 Notch Sensitivity

A sharp corner in a fabricated part or a notch in a test specimen can dramatically lower the impact strength of the material. This is because a notch creates a localised stress concentration where the true stress can be many times higher than the bulk stress being imposed on the test piece or object as a whole. Hence failure under impact loading is promoted. All plastics are notch-sensitive, but the notch sensitivity varies with the type of plastic being considered. Both notch depth and notch radius have an effect on the impact behaviour of materials. A larger radius of curvature at the base of the notch will have a lower stress concentration and therefore will tend to give a higher impact energy for the material in question. It can be seen from this that when designing a plastic part, notches, sharp corners, and other factors that act as stress concentrators should be avoided. The science of fracture mechanics seeks to quantify these types of effects and the interested reader is referred to [7] for an overview of the subject, [8] provides a more detailed development of the mathematical concepts and [9-17] give information on particular aspects of the subject.

10.1.3.4 Fillers

The inherent impact properties of a polymer may be modified simply by adding some form of filler. Polymeric impact modifiers may be incorporated to act as barriers or crack blunting regions to the advancing crack front. A good example of this is the addition of polybutadiene (PB) rubber to styrene-acrylonitrile (SAN) plastics to produce ABS. In other instances lower molecular weight plasticisers are added (for example to polyvinyl chloride (PVC)) to improve the impact behaviour. In the case of Nylons, increasing the moisture content significantly improves the toughness of the plastic. Very dry Nylons like Nylon 6 and 6-6 are quite brittle and sufficient time must be allowed for them to gain atmospheric moisture prior to testing if the 'equilibrium' impact strength is to be measured. The down-side of plasticisation is that it results in loss of rigidity. Another way to improve the impact strength may be to use fibrous fillers that appear to act as stress transfer agents. Good coupling between the fibre and the polymer matrix is necessary for the effect to take place. Other fillers may be used simply to make the product cheaper and typically these result in some impairment of impact strength compared to the base resin. Recent papers which consider some of the aspects of fillers on impact properties include calcium carbonate [18, 19], pigments [20], glass beads [21], glass fibres [22, 23] and talc [24] on polypropylene (PP), mica on polybutylene terephthalate (PBTP) and Nylon [25] and alumina particles in epoxy resins [26]. Effects of moisture on Nylon are given in [6] and on polycarbonate in [27].

10.1.3.5 Orientation

Polymer molecules are long 'spaghetti-like' structures and as such their orientation within an object is highly dependent on the flow patterns of the molten polymer during the moulding phase. The properties of the molecules themselves are also highly directional: properties along the main backbone chain are quite different to those along side chains and between the molecules. For this reason, the manner in which the polymer molecules are oriented in a part will have a major effect on the impact behaviour of the polymer - the impact strength is always higher in the direction of flow. Molecular orientation is deliberately introduced by drawing films and fibres, for example, to give extra strength and toughness along the stretch direction compared to the isotropic material. However, at right angles to the flow or drawing direction the impact properties can be significantly reduced as it is predominantly inter-molecular forces rather than intra-molecular forces that are involved. Such directional orientation of polymer molecules can result in dramatically different impact properties in different areas or directions of a moulded part. Impact stresses are usually multiaxial and so tend to automatically 'find' the weakest direction in the moulding.

10.1.3.6 Processing Conditions

Processing conditions also play a key role in determining the impact behaviour of a material. Inappropriate processing conditions can cause the material to fail to attain its inherent toughness. Poor processing conditions may create voids, for example, that will act as stress concentrators; high processing temperatures may cause thermal degradation and, therefore, reduce the impact strength; inadequate drying of plastics that have a tendency to absorb moisture can have a dramatic effect in reducing the resulting impact strength. Improper mould design may create a weak weld line that will almost certainly reduce the overall impact strength. Test pieces taken from compression-moulded plaques usually show a lower impact resistance than test pieces that are directly injection-moulded and test pieces with moulded notches give higher impact strengths than test pieces with machined notches [28]. Some of the effects of annealing can be found in [29], and of weld lines in [30, 31]. Rotational moulding is discussed in [32] and the processing variables of reaction injection moulding (RIM) in [33]. Processing temperature effects are given in [34] and the issue of reprocessing/recycling is covered in [35]

10.1.3.7 Molecular Weight and Degree of Crystallinity

All other things being equal, a reduction in the average molecular weight reduces the impact strength and *vice versa*, although above a certain critical molecular weight the effect is relatively slight. The papers by Ibhadon [29] and Schriver and co-workers [35] include the influence of molecular weight on impact properties.

For semi-crystalline plastics, like polyolefins, increasing the percentage crystallinity decreases the impact resistance and increases the probability of brittle failure, so the thermal history of the product will influence the outcome of an impact event. Material that has been quenched from the melt will be tougher than the same material that has been allowed to cool slowly. The crystallinity and molecular weight effects for polyether ether ketone (PEEK) is dealt with in a paper by Chivers and Moore [36].

10.1.3.8 Impact Methodology

The geometry of the test piece and the manner in which the test piece is struck can significantly alter the impact results. Thus a pendulum impact test will produce a different result from the one produced by falling-weight. What is more surprising to many people who are not familiar with the complexity of plastics materials is that different types of pendulum test, e.g., Charpy and Izod, also produce different results and there is no simple correlation between them. Although these pendulum tests 'normalise' the impact energy for a given test piece by dividing the energy taken out of the pendulum by the cross sectional area behind the notch, it is found that different sized test pieces tend to give different impact data. All of this makes the application of impact data into design calculations in a direct, quantitative, way fraught with difficulty. It also means that even when simply comparing databases for materials we must be sure we are comparing like with like or false conclusions will inevitably follow. Mention may be made in this context of the use of ISO standard protocols for the generation of single point data [37] and multipoint data [38] and of the Campus [39] system of representing comparable data from different materials producers. A comparison between pendulum devices and drop weight impact tests for long glass fibre reinforced PP has been made by Paakkonen and co-workers [23] and the effect of geometry on pipe grade plastics by Douglas and Leevers [3]. Rogers and Plumtree [40] compare the Izod and Charpy tests for polystyrene (PS).

10.2 Specific Tests

As has been touched on previously, the impact testing of plastics tends to fall into two basic categories: the pendulum tests and the falling weight tests. Each of these may then be further sub-divided into more specific classes.

10.2.1 Pendulum Methods

10.2.1.1 Charpy Test

The Charpy test is detailed in BS EN ISO 179-1 [41], and the related ASTM D6110 [42]. The following discussion is based on the ISO test method, with comments on the ASTM variant at the end.

In the Charpy test the test piece is supported as a horizontal beam and is broken by a single swing of a pendulum, the line of impact being midway between the supports. Both notched and unnotched test pieces may be tested and the test piece may be oriented in the edgewise or the flatwise direction. The two geometries are illustrated in **Figure 10.1**.

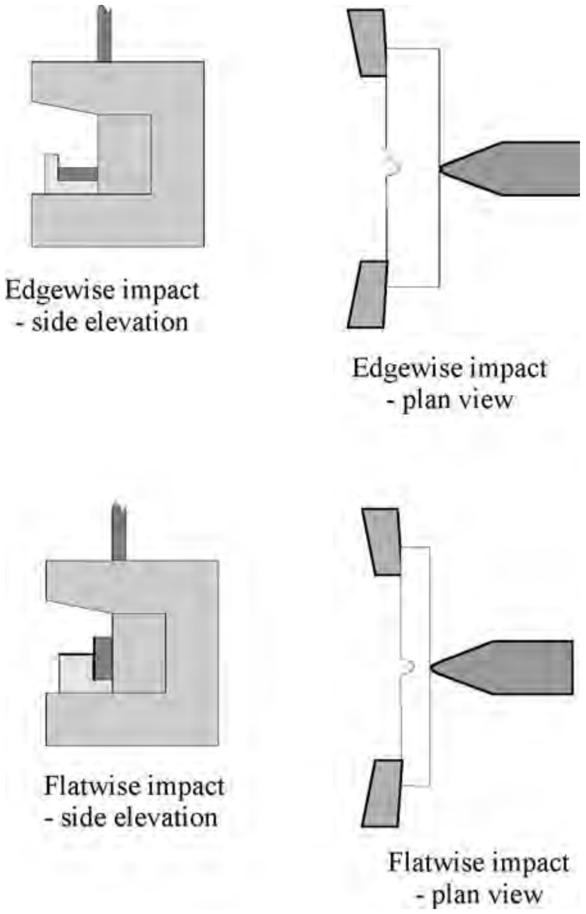


Figure 10.1

The directionality of the test is best understood in relation to the test piece dimensions themselves. The standard test bar is 80 x 10 x 4 mm which can be cut from the centre parallel portion of the multipurpose test specimen [43]. In the flatwise test the direction of the pendulum at impact is in the 4 mm direction of the test piece so that bending takes place over the 80 x 10 mm surface. In the edgewise test it is the 80 x 4 mm plane that is bent and the pendulum travels in the direction of the 10 mm dimension. The edgewise test is now the preferred form of geometry for most testing purposes. In former times it was the flatwise test that was typically used and the edgewise test was reserved for investigating the effect of fibre-reinforcements on impact strength. Now the flatwise test is reserved for investigating surface effects such as might occur when the material is weathered by UV light or exposed to chemicals.

For laminated test pieces tests may be performed both flatwise or edgewise and for each of these there exists the possibility of having the laminations parallel or normal to the direction of blow. These variations are illustrated in **Figure 10.2**. All of these are permitted and a suitable coding scheme is defined to enable the options chosen in a given test to be defined very succinctly.

The test can be performed using either unnotched or notched test pieces, although the notched test is the more common. Three types of notches are standardised (**Figure 10.3**), the preferred one having a radius at the notch base of 0.25 mm (the type A notch). A blunt 1.0 mm (type B notch) and a very sharp 0.1 mm (type C) notch are also covered. Notches of different base radius are useful for more extensive characterisation of plastics than a simple quality test or data sheet entry, in that they enable an estimate of the notch sensitivity of the plastic to be investigated, as was mentioned in 10.1.3.3. The flatwise test can also be performed notched or unnotched, except here the notched test has two notches machined across the 4 mm direction and directly opposite each other to give a 6 mm width to the test piece between the notches. All three types of notch may be used in the edgewise test.

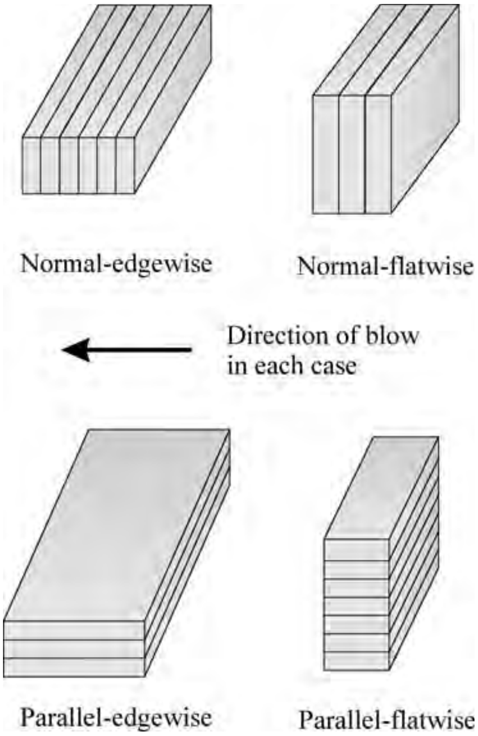


Figure 10.2

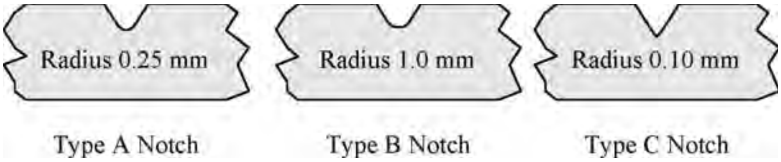


Figure 10.3

The standard test piece is suitable for general purpose testing, although where sheet material is to be tested it is permissible to test the full thickness of the sheet up to a maximum of 10.2 mm. Above this the sheet should be machined on one surface to reduce the thickness to 10 mm. Where the sheet is reinforced in some way the reinforcement must be regularly distributed and be of only one type. Thin samples are not suited to this test as buckling of the test piece can occur when tested edgewise or bending without failure when tested flatwise. For long-fibre reinforced plastics alternative geometries are permitted that have no specified specimen sizes. Instead it is the span to thickness ratio that is the controlling parameter. For type 2 test pieces the L/h ratio is 20 and for type 3 a ratio of 6 is preferred, however where thinner sheet materials are being tested and the apparatus does not allow such a small ratio to be accommodated, then a ratio of 8 is permitted. The test piece width for a flatwise test is either 10 mm or, for large stitch or irregularly manufactured structures this is increased to 15 mm. When an edgewise test is performed the dimension perpendicular to the direction of impact is that of the sheet from which the test piece has been machined.

The ISO standard covers two pendulum lengths, giving different velocities at the point of impact. The one most frequently used has an impact velocity of 2.9 m/s and five pendulums having energies of 0.5, 1.0, 2.0, 4.0 and 5.0 J are specified. The larger machine, having an impact velocity of 3.8 m/s, has pendulums of energy 7.5, 15.0, 25.0 and 50.0 J.

The impact strength is the energy removed from the pendulum as a result of work done in breaking the test piece divided by the cross sectional area of the test piece in the direction of swing. In fact, because the test piece is bending during the impact event, there is a deformation volume rather than simply an area and so test pieces of different size do not give results which are proportional to the cross-sectional area, but rather to some indeterminate volume. For this reason results obtained from test pieces of different size cannot be compared.

The ASTM D6110 [42] test follows the same principles, but differs in detail, as the first note of the standard points out. The preferred test specimen dimensions are based on imperial units, but unfortunately the current version of the standard contains an error such that the Figure referred to as giving the test piece dimensions actually gives the geometry of the anvil used for the micrometer. It may, however, be inferred that the preferred test piece is probably

127 mm long, by 12.7 mm wide by a thickness between 12.7 and 3 mm. The span between the supports is 95.3 mm compared to the ISO standard of 62 mm. The details of the apparatus used are the same as for the Izod test which is covered in the Section 10.2.1.2. Unlike the ISO test, the preferred form of expressing the result is different being based on the energy normalised with respect to the length of the notch only, and not on the area behind the notch. The alternative normalisation with respect to area is also now permitted. This only serves to add to the difficulty in making comparisons between data obtained by the ASTM standard, with its different test piece sizes and impact conditions, to that of the ISO standard.

BS EN ISO 179-2 [44] covers the instrumentation of the Charpy pendulum so that force-time (and by integration, force-deflection) curves can be obtained. This allows for a fuller characterisation of the impact behaviour of the plastic than can be derived only from the energy to break of the typical test. Otherwise the test procedure follows much the same details as for the non-instrumented version, the same test piece sizes being used and the 2.9 m/s pendulum being the preferred one. There has been an instrumented version of the falling weight impact test (see later in this section) for several years and the same principles apply to both.

Nakamura and co-workers [45] have used the instrumented Charpy test to examine the effect of silica fillers on epoxy resins while Wang and co-workers [46] have used the same technique for examining RIM parts. Trantina and Oehler [47] discuss the application of Charpy (and Izod) tests to the prediction of impact resistance for use in design calculations. Sharpe and Boehme [48] have used a small Charpy test to investigate dynamic fracture toughness measurements.

10.2.1.2 Izod Test

The Izod test is notionally very similar to the Charpy test, except that the test piece is clamped at one end just below the notch, or the centre of the specimen if it is unnotched, and struck by a pendulum close to the other end. It is therefore a cantilever bending test (**Figure 10.4**). Traditionally the Izod test has been more favoured in North America, while the Charpy test has been more popular in Europe. The test details are given in BS EN ISO 180 [49] and ASTM D256 Method A [50] (also methods C, D and E).

Considering the ISO standard first, the standard test piece is the ubiquitous 80 x 10 x 4 mm test piece taken from the multipurpose test piece [43] so widely used in ISO. Three variants are permitted: unnotched, notched with a 0.25 mm radius notch (type A) or notched with a 1.0 mm radius notch (type B). These match the same conditions as for Charpy, but the type C notch is undefined for Izod. The test is almost always carried out edgewise, although where laminated plastics are to be tested it is possible to test flatwise as well and using the same parallel or normal arrangements as for Charpy.

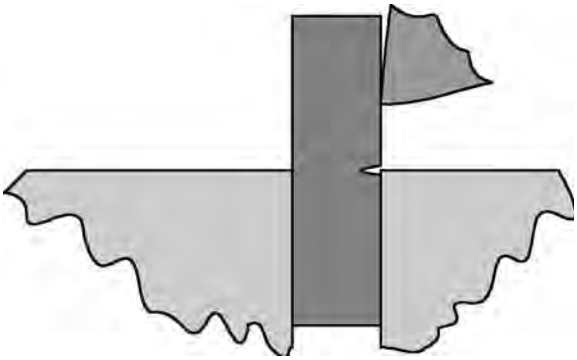


Figure 10.4

Unlike the Charpy test, the notched Izod is capable of being tested either with the notch on the same side as the point of impact, which is the normal way round, or on the opposite side when it is called the reverse notched test. Thus, in the normal test the side containing the notch is placed under tension and the notch fulfils its purpose as a stress concentrator. In the case of the reverse notch it is the unnotched face which is under tension and no stress concentration occurs; in fact the notch is placed under a compressive deformation. This arrangement is possible in the Izod because the pendulum strikes the test piece at a point remote from the notch and the advantage of having the reverse notch is that the test piece is otherwise identical. For the Charpy test the cross section of the unnotched test piece must be greater than the notched test piece.

The impact velocity for the test is 3.5 m/s and pendulums of energy 1.0, 2.7, 5.5, 11.0, and 22.0 J are used. As for the Charpy test, the energy absorbed by the impact should be between 10% and 80% of the capacity of the pendulum.

Certain plastics can give results which vary according to clamping pressure, a problem from which the Charpy test is free, and the standard recommends that when testing such materials some means of standardising and recording the clamping pressure should be used. However, it gives no advice on which plastics are so affected nor on how to determine whether the effect is significant or not.

The test is often applied to plastics at sub-ambient temperatures but is far from ideal for this. Again, the Charpy test is preferred. There are serious practical problems in carrying out the test with the apparatus itself at the low test temperature due to icing of the bearings, etc. It is therefore common practice to soak the test piece at the test temperature and then quickly remove it and test it. However, the test piece must be clamped into a large metal heat source, the clamping vice, at a point adjacent to the critical notch region where the bending takes place. The actual test temperature is therefore quite indeterminate and likely to be variable from test piece to test piece.

The ASTM test follows the same principles, but, as for the Charpy test, differs in certain details. Again, the test is based on imperial units with the preferred impact resistance characterised by the length of the notch rather than the area behind the notch. The details of the apparatus itself mirror very closely the requirements of the ISO test method which was largely derived from the ASTM standard. Method A covers the normal test procedures which are applied to materials having an impact resistance in excess of 27 J/m. For lower values than this, Method C is applied which attempts to make a correction for the energy required to 'toss' the test piece. This involves carrying out a secondary test on the broken test piece, wherein the halves of the test piece are reassembled and the energy value obtained when this broken test piece is impacted is taken to be the energy absorbed in accelerating the initially stationary test piece. Since this energy is not due to the impact event as such, it is then subtracted from the apparent energy obtained during the first impact event, when the test piece was unbroken. Objections to the scientific principles behind this idea can be raised, and it has never found acceptance within the ISO community.

Method D deals with the estimation of notch sensitivity by having the test carried out at two notch radii, 0.25 mm and 1.0 mm. The ratio of the difference in the two energy values to the difference in notch radii is then taken as the index of notch sensitivity. Where the 1.0 mm radius leads to test pieces which do not break, a 0.5 mm radius notch may be substituted.

Method E covers the reversed notch test and although this is intended to represent an unnotched test piece, the standard warns that this method may not give identical results to a completely unnotched test piece. Genuinely unnotched test pieces are covered in the method given in ASTM D4812 [51] which is stated to be particularly suitable for testing reinforced materials, where a notch may mask the effects of orientation.

ASTM D4508 [52] is an Izod-like cantilever beam test but using a small test piece, 19.05 mm long by 12.7 mm wide and 1.02 to 3.18 mm thick (1.8 mm is preferred). It appears to be particularly favoured for assessing the effect of weathering on the impact resistance of plastics and for testing test pieces taken from finished products, where its small size is a significant benefit. There is no near-equivalent in ISO to this test.

Fu and co-workers [53] have investigated the toughening of polyethylene by calcium carbonate using the Izod test while Grocela and Nauman [54] have tried to derive quantitative models for Izod to predict strength for impact modified PS. The Izod test has been used to investigate the toughening mechanism of low molecular weight PB in PS [55, 56]. Weier and Hemenway [5] describe the use of the instrumented Izod test on PVC/acrylic composites.

10.2.1.3 Tensile Test

Both the previous two methods require the test piece to be sufficiently rigid for buckling of the specimen under test to be negligible. For thinner section materials and for those exhibiting a high elongation before fracture, the tensile impact test may be the only viable pendulum method. The test is standardised in BS EN ISO 8256 [57] and ASTM D1822 [58].

There are two basic types of tensile impact test: the specimen-in-bed type (illustrated schematically in **Figure 10.5**) and the specimen-in-head type. Method A of ISO 8256 covers the first of these and Method B the second. Two pendulum lengths are given in the standard, one of which gives an impact velocity of 2.8 m/s and the other of 3.7 m/s. The former is applied to pendulums having an energy of 2 and 4 joules, while the latter is applied to pendulums having an energy of 7.5, 15, 25 or 50 joules.

For Method A the test piece is clamped into a suitable holder mounted onto the bed of the apparatus. One end of the holder is rigidly mounted on the bed and the other, the cross-head, is free to move along the bed. The test piece forms a bridge between them. A pendulum is released and at the bottom of its swing it makes contact with the arms of the cross-head. Kinetic energy is transferred to the test piece which extends to rupture and the absorbed energy is determined from the height of swing of the pendulum. However, some energy is also expended in tossing the cross-head and so a correction must be

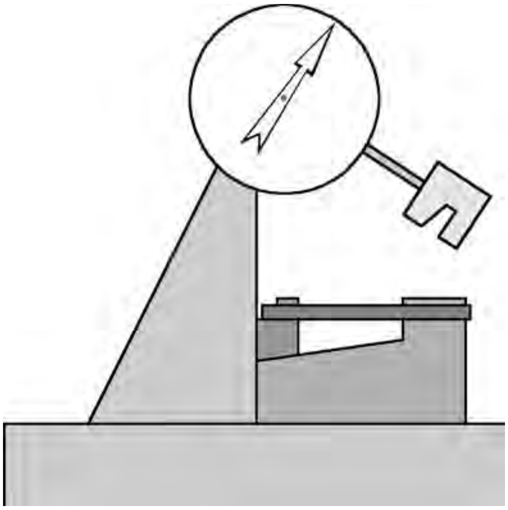


Figure 10.5

applied for this. The correction is a constant for a given pendulum and cross-head and can be determined from the equation:

$$E_q = \frac{E_{\max}\mu(3+\mu)}{2(1+\mu)}$$

where $\mu = \frac{1}{4}\frac{m_{cr}}{E_{\max}}\left(\frac{gT}{\pi}\right)^2\left(1-\cos\alpha\right)$

E_q is the energy correction due to the plastic deformation and the kinetic energy of the crosshead;

E_{max} is the maximum impact energy of the pendulum;

m_{cr} is the mass of the crosshead;

g is the acceleration due to gravity;

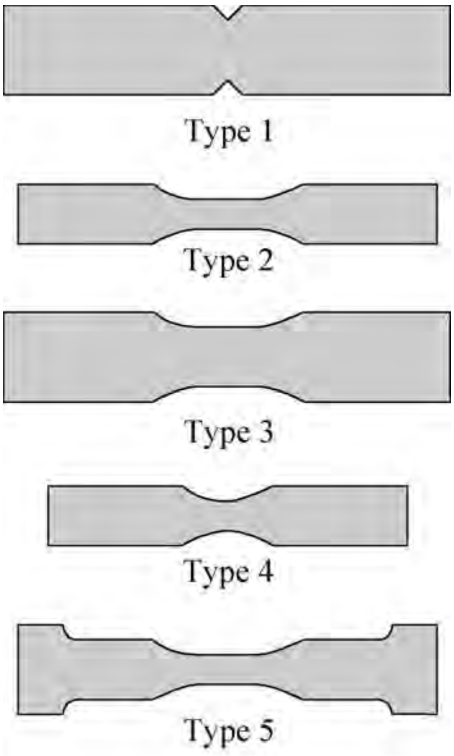
T is the period of the pendulum;

α is the angle between the positions of the maximum and minimum height of the pendulum.

The desired energy to rupture the test piece is then simply the difference between the uncorrected energy read from the maximum swing of the pendulum after impact and the above correction energy. As for the Charpy and Izod tests the result is normalised with respect to the area of the test piece cross-section, although unlike the other pendulum impact tests, there are several types of test piece that are used (see **Figure 10.6**).

For Method B the test piece is clamped into the compound head of the pendulum which is released from its raised position. As it reaches the lowest point of its swing the rear of the pendulum strikes rigid supports on the frame of the apparatus and is arrested. The front of the pendulum continues its swing, extending and rupturing the test piece. As for Method A, corrections must be applied to the energy read from the swing of the pendulum to compensate for the crosshead bounce energy. In this case the correction is added to the reading from the pendulum because immediately after impact the two halves of the pendulum are travelling in opposite directions. The correction for a given apparatus is determined by means of a special calibration procedure which is detailed in the standard.

ASTM D1822 is essentially Method B of the ISO standard, the specimen-in-head geometry being that favoured in North America, while the specimen-in-bed geometry has been typically favoured in Europe.



Type 1

Type 2

Type 3

Type 4

Type 5

Figure 10.6

Tensile impact has been used to characterise the effect of molecular weight on impact and stress-strain properties [59] while Dijkstra and co-workers [60] have used tensile impact to investigate the toughening effects of rubber in Nylon 6.

10.2.2 Drop Methods

10.2.2.1 Falling Dart Methods

The traditional falling dart methods require a large number of test specimens because for each drop there can be only two outcomes: the test piece fails according to some agreed criteria, or it passes. The amount by which it passes or fails cannot be judged. Results must therefore be analysed statistically in order to quantify the mean energy or mass or height which causes failure. With the newer methods, piezoelectric or resistive transducers are built into the dart so that the force during impact can be monitored directly and a quantitative result obtained for each test piece tested.

The general test for plastics is covered in BS EN ISO 6603-1 [61]. Test pieces of preferred size 60 mm square (or circular) by 2 mm thick are supported on an annular base of inside diameter 40 mm and the dart with a 20 mm diameter striker is released from a preferred height of one metre. The test piece may be clamped or unclamped on the support, although the standard indicates that different results are likely to occur from these two techniques and it is permitted also to use a 10 mm diameter striker.

Two methods of analysis are covered. The preferred method is the 'staircase' method in which the mass of the dart is varied in given increments according to whether the test piece previously tested passed or failed. If it passed, the mass is increased to increase the probability of failure next time, and if it failed, the mass is decreased to decrease the probability of failure. At least 20 test pieces are required plus an additional 10 used as preliminary specimens to select a suitable starting mass and increment. The increment by which the mass is changed must be kept constant throughout a given test run. In Method B, the 'statistical' or 'probit' method, a minimum of 40 test pieces is required, although in practice 60 or more tend to be needed. Here 10 test pieces are tested under given conditions and the percentage of failures recorded. The mass is then altered and a further 10 are tested and so on until at least three results are obtained with percentage failures greater than 0% and less than 100% with at least one result greater than 50% and at least one result less than 50%. In this test non-uniform increments of energy can be used so it is easier while the test is underway to ensure that a more even spread of results can be achieved.

For both tests it is permitted to vary the height rather than the mass, although this is not the preferred way to carry out the test as impact velocity is changing along with the impact energy. The variable falling height method is given for the testing of plastics pipes in BS EN 1411 [62], which is also dual numbered as BS 2782 Method 1108B [63].

The mean impact strength and standard deviation are determined by means of a rather complex calculation for the staircase method or for the statistical method by plotting the percentage passes (or failures) against impact parameter (energy, mass, or height according to the requirements) on probability paper and finding the best fit straight line. The parameter which corresponds to the 50% failure probability is the mean value and the difference between the 50% and the 16% (or the 84%) probabilities is the standard deviation.

The method detailed in ASTM D5420 [64] is somewhat unusual compared to other impact standards in that the test piece, which is placed on a support plate having a circular hole of given size, has a striker resting upon it and the striker is then impacted by the falling weight. This is the so-called Gardner impact test and a number of variations in geometry are allowed. It uses the 'staircase' approach to varying the energy of impact, with drop height rather than the drop mass being varied. ASTM D5628 [65] is rather more conventional and follows the same pattern as ISO 6603-1, albeit with different dart shapes and drop height.

Films and sheeting are tested by similar methods, although the test piece diameter tends to be rather larger, typically 125 mm or so, as does the impacting striker. The standardised tests are given in ISO 7765-1 [66], and the identical BS 2782 Method 352E [67], and in ASTM D1709 [68]. There is very little difference between these standards, although the ASTM method does permit either the staircase or the probit method of analysis while the ISO and BS only allow the staircase method to be used. The drop height is either 0.66 m for method A or 1.5 m for method B.

Instrumented impact tests are cited in BS EN ISO 6603-2 [69] for general purpose plastics testing and ISO 7765-2 [70] for films and sheeting. These tests are echoed in the corresponding BS 2782 Method 352F [71], which is identical to the corresponding ISO. The essential difference to the non-instrumented variant is that some load sensing transducer is built into the dart; it is preferable to have this transducer as close to the point of impact as possible to reduce interference from 'ringing' effects as the force wave sweeps up the dart from the moment of contact. **Figure 10.7** gives a schematic illustration of the dart arrangement. The transducer is generally a resistive or piezo-electric device, the latter being preferred as it has a higher natural frequency and is therefore capable of recording faster transitions without attenuation of the signal.

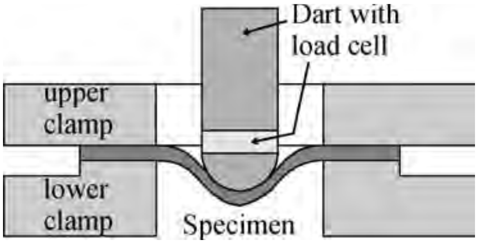


Figure 10.7

Much of the detail concerning test pieces and geometry are as given in ISO 6603-1. It is noteworthy that for the film and sheeting tests, the same 40 mm span is used as for the general test and not the much larger span of 125 mm as in the non-instrumented test. Much of these standards is devoted to the requirements for the instrumentation - the frequency response of the transducer and the band-width of the amplifier to ensure that attenuation or distortion of the signal generated by the impact event are not significant. For the instrumented option, the dart should have a large excess of energy so that the reduction in velocity during impact is small (less than 20%). This is unlike the simple falling weight test, where the energy of the dart has to be similar to the impact energy of the material being tested.

In addition to the impact energy, this test is also capable of delivering the peak force, the energy to peak force and the displacement at peak force. The shape of the force-displacement curve can itself be instructive in characterising the material's behaviour, and the standards give several examples of the type of curve that may be observed, as well as various failure criteria that can be applied. Clearly, therefore, much more data can be derived from this test than is possible from the simple test. It also requires far fewer test pieces: 10 is the norm, but for quality purposes five may be used. The negative side, of course, is that the apparatus is much more expensive and cannot be put together with a minimum of workshop facilities, as can the simple test.

ASTM D3763 [72] follows similar principles to ISO 6603-2 but with differences in striker, fixture, specimen geometry and impact velocity it is hardly surprising that the methods give different numerical values. Suggested impact velocities are 2.5, 25, 125, 200 and 250 m/min. A 12.7 mm dart impacts a test piece of diameter between the inside of the clamp faces of 76 mm.

A particular variation on the non-instrumented falling dart method which is applied to plastics pipes is the 'round-the-clock' method in which the same test piece (a 200 mm long section of pipe) is struck repeatedly at several points around its circumference. The number of impacts per test piece varies according to the diameter of the pipe. For pipes of less than 40 mm nominal size a single blow is administered. This then increases to three for pipes up to 63 mm and so on until 24 impacts are delivered to pipes of nominal size exceeding 355 mm. The impact 'resistance' is measured as the true impact rate (TIR) which is the total number of failures divided by the total number of blows, expressed as a percentage. This technique is standardised in BS EN 744 [73] which is the same as BS 2782 Method 1108C [74] and the older but very similar BS 2782 Method 1108A [75]. In each of these the maximum acceptable value for TIR is 10%. Since the TIR must be established with at least a 90% level of confidence, a very large number of impacts (several hundred) may be required for a pipe that is at all borderline. There must be at least 25 impacts as a minimum.

In ASTM D3420 [76] a pendulum impact test on plastics films is detailed. A 12.7 mm diameter dart-ended pendulum is released from a height which gives an impact velocity of 74 m/min and the energy absorbed from the pendulum as a result of the impact is measured by means of an indicating follower. As with many ASTM standards there are two variants of the apparatus with different manufacturers supplying one or other of the types.

10.2.2.2 Falling Product Methods

As well as tests on materials, impact tests may also be applied to finished products. BS 6642 [77] for example is a specification for plastic refuse sacks, although the specification has now been declared obsolescent by BSI. One of the tests therein is an impact test in which the sack is partially filled with sawdust and dropped through a hang-man's trap door. Objects such as milk crates and chemical-containing drums are also frequently tested by loading the object in a way that simulates service and then releasing them from a given height – often at various angles, for corner, edge and face impacts – onto a firm foundation such as concrete. The test is often carried out at sub-ambient temperatures to characterise the behaviour under service conditions that might lead to more brittle failures.

ASTM D2463 [78] is applied to blow-moulded containers and essentially consists of a spring-loaded platform upon which the container rests at a pre-arranged height above the impacting surface (a 13 mm thick steel plate). The platform is released from its horizontal plane and falls rapidly away from the container so as not to impede its drop. In Method A, 20 containers are released from an agreed height and the number of failures recorded (primarily used for quality control purposes as it is a rapid test). In Method B the drop height is varied (The Bruceton Staircase method) about the approximate mean height to cause failure and the mean height to cause failure and the standard deviation are then calculated. ASTM D4504 [79] for open pails includes drop tests as does ASTM D1185 [80] for pallets.

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