Lecture 42- Polymer Testing 07

Hello friends, welcome to the Mechanical Properties section within the realm of Polymer Testing. In this segment, we will delve into the topic of impact strength. Previously, we've explored various mechanical properties such as shear properties, including lap or sandwich tests, and discussed standard test methods. Additionally, we've covered flexural properties like flexural strain, stress-strain tests, three-point loading, four-point loading, and the cantilever test standards. Now, let's focus on impact strength.

Impact strength plays a crucial role in the determination and characterization of polymer samples' properties. The overall toughness of a plastic material is directly linked to its impact characteristics. Understanding toughness is relatively straightforward, as it's commonly defined as the amount of effort required to shatter a test piece or object. One of the significant advantages of impact testing is its ability to provide a quick estimate of the actual energy needed to break the test component.

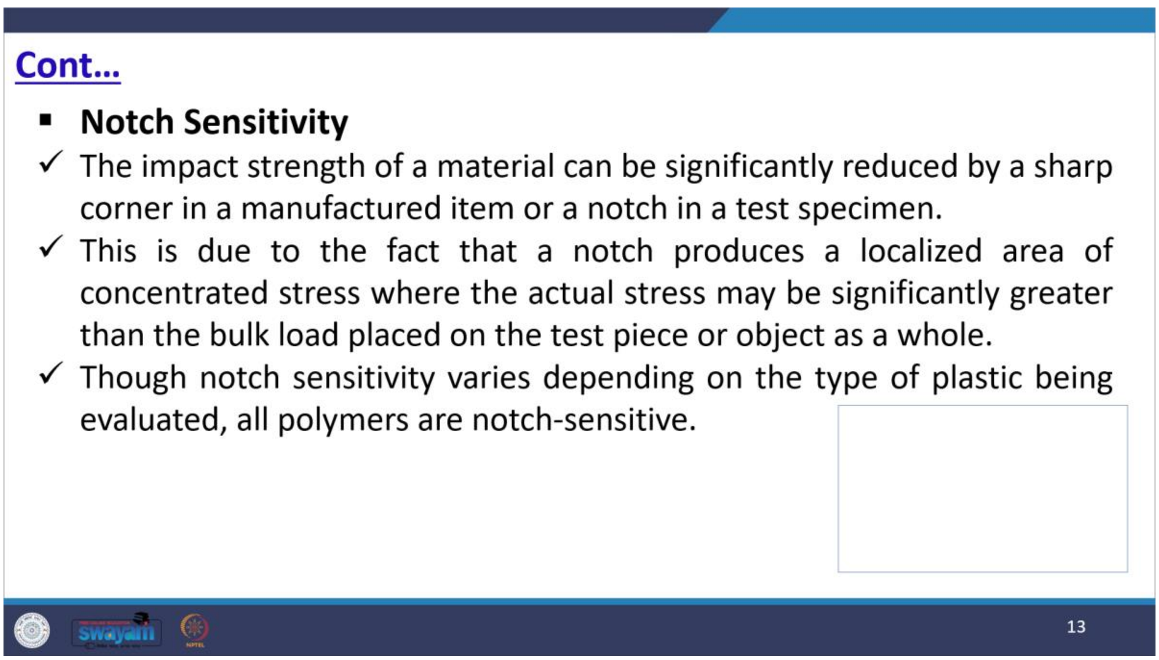
Both initiating and propagating a crack through a material require energy. The energy needed to start a crack is known as crack initiation energy, and if the available energy surpasses this threshold, the crack will propagate, leading to complete failure. Impact energy, therefore, results from both crack initiation and propagation. Under impact, four common types of failure can occur, each with distinct characteristics.

Brittle fracture is characterized by wide fracturing without deformation, often leaving a sharp or glassy edge. Materials like general-purpose polystyrene frequently exhibit this type of failure under impact conditions. On the other hand, ductile failure involves noticeable material yielding, often indicated by stress widening alongside cracking. Polyolefins are typically considered ductile materials, with yielding resulting in irreversible deformation and stress whitening but no cracking.

Mild cracking occurs when a part shows some cracking and yielding but maintains its shape and integrity. Several factors affect impact strength, one of which is the rate of loading. Because plastics are viscoelastic, the speed at which the test piece or component is struck significantly influences how the polymer responds to impact loading. Even rubbery materials can exhibit brittle failure at high impact rates, while relatively stiff materials may still demonstrate considerable impact strength at low impact rates.

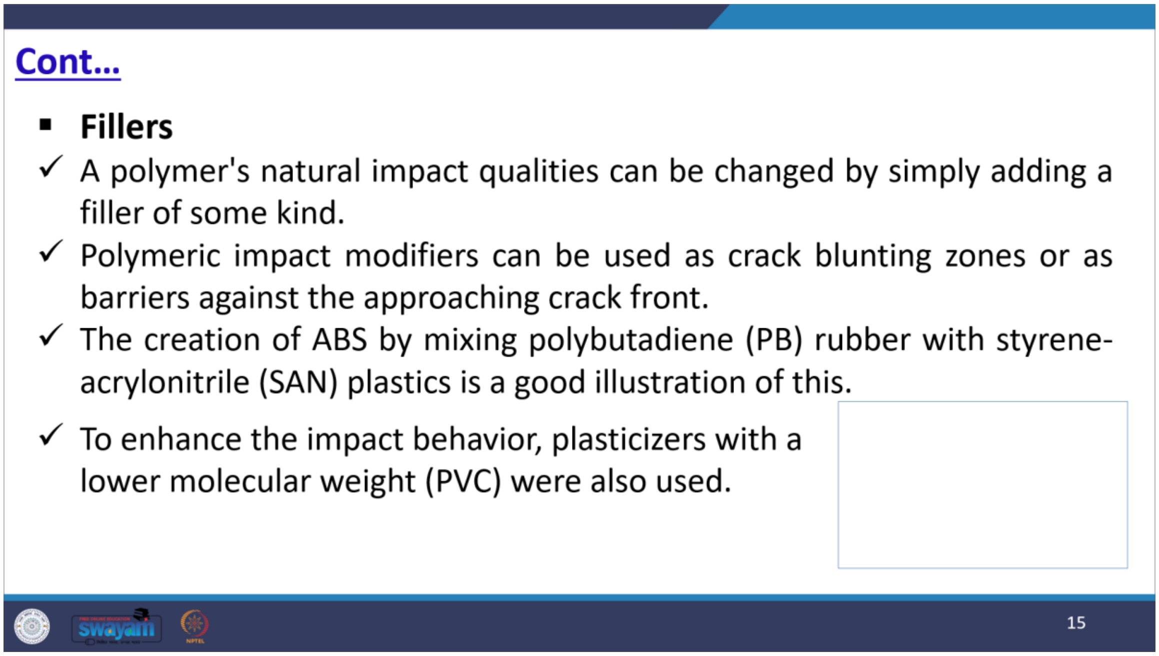
There seems to be a critical velocity beyond which all polymer materials become glassy and brittle. Relying on standard impact tests like Charpy or falling weight for material selection becomes risky if a product will experience impact speeds much higher than those tested. Materials that behave ductilely at lower speeds may become brittle at application speeds. Thus, while these tests can screen potential candidate materials, more specialized and ad hoc tests may be necessary, such as shooting a projectile at the material.

Temperature is another crucial factor influencing impact strength, particularly for plastics, whose viscoelastic nature makes them more temperature-sensitive than metals and ceramics. Lower temperatures tend to accelerate brittle failure development. Therefore, it's essential to consider the temperature range the item will encounter during use and conduct impact testing across this range as practically as possible. It's noteworthy that temperature changes have the opposite effect on speed, meaning the transition from ductile to brittle behavior occurs within a range of temperature or speed values rather than at a single temperature.



Notch sensitivity is a critical consideration in assessing a material's impact strength, as sharp corners or notches in test specimens can significantly reduce it. This reduction occurs because notches create localized areas of concentrated stress, where the actual stress may exceed the bulk load applied to the test piece. While the extent of notch sensitivity varies depending on the type of plastic being evaluated, all polymers exhibit some level of notch sensitivity. The impact behavior is affected by both the depth and radius of the notch, with materials typically exhibiting higher impact energy when there's less stress concentration and a larger radius of curvature at the notch base.

Avoiding notches, sharp corners, and stress-concentrating elements is essential when designing plastic items to maintain their impact resistance. Polymer impact modifiers can alter a polymer's natural impact characteristics by introducing fillers, which change its mechanical properties. These modifiers can act as crack-blunting zones or barriers against crack propagation. For instance, the creation of ABS (Acrylonitrile Butadiene Styrene) involves blending polybutadiene rubber with styrene acrylonitrile (SA-N), illustrating this approach.

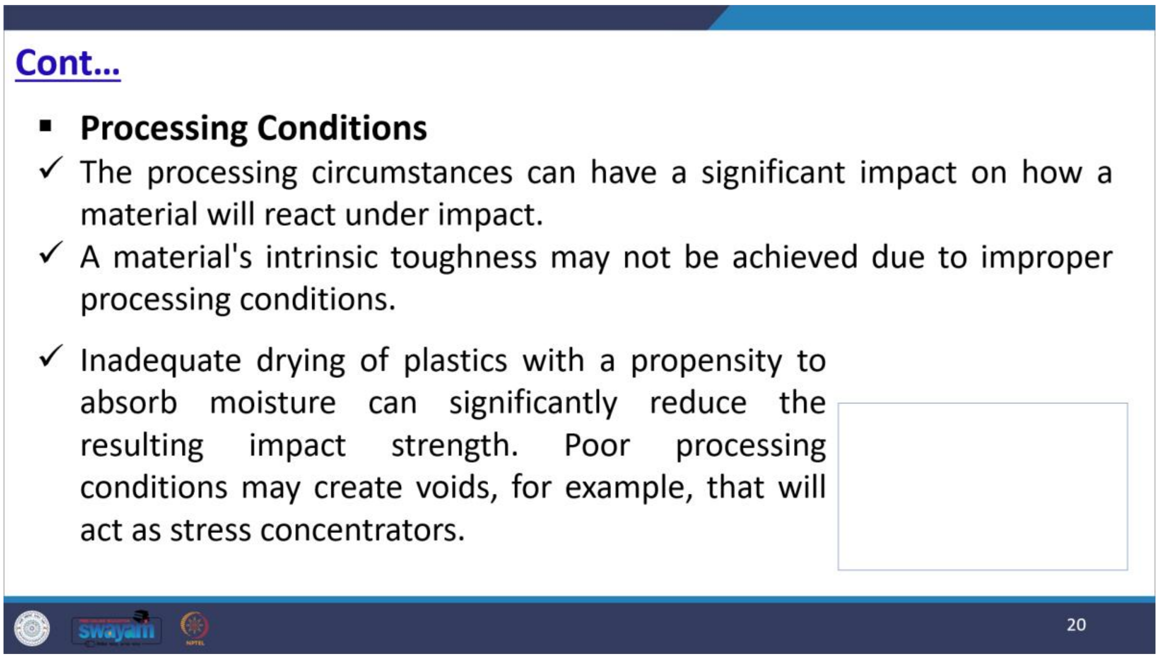


Additionally, plasticizers with lower molecular weights are utilized to enhance impact behavior. Increasing moisture levels, particularly in materials like nylon, can significantly improve plastic toughness. However, for nylon variants such as nylon 6 and 6-6, sufficient time for air moisture absorption is necessary before testing to prevent high fragility. While acidization can enhance impact strength, it may lead to stiffness loss. Fibrous fillers, acting as stress transfer agents, can also boost impact strength.

The orientation of polymer molecules profoundly influences the impact behavior of plastic materials. During the molding process, the flow pattern of molten polymer determines how molecules are arranged within an object. Due to their elongated, spaghetti-like structure, polymer molecules exhibit directed properties, with qualities along the main backbone chain differing from those across chains and molecules. Consequently, the impact strength is typically greater in the direction of flow. Purposeful orientation, achieved through processes like drawing films and fibers, enhances material toughness in the stretch direction compared to isotropic materials.

However, impact qualities can be significantly diminished perpendicular to the flow or drawing direction, where intermolecular forces dominate over intramolecular forces. The impact characterization of a molded part may vary across different orientations due to the directional orientation of polymer molecules. Impact stresses are often multiaxial and tend to exploit the mold's weakest direction. Additionally, processing conditions play a crucial role in determining a material's response to impact.

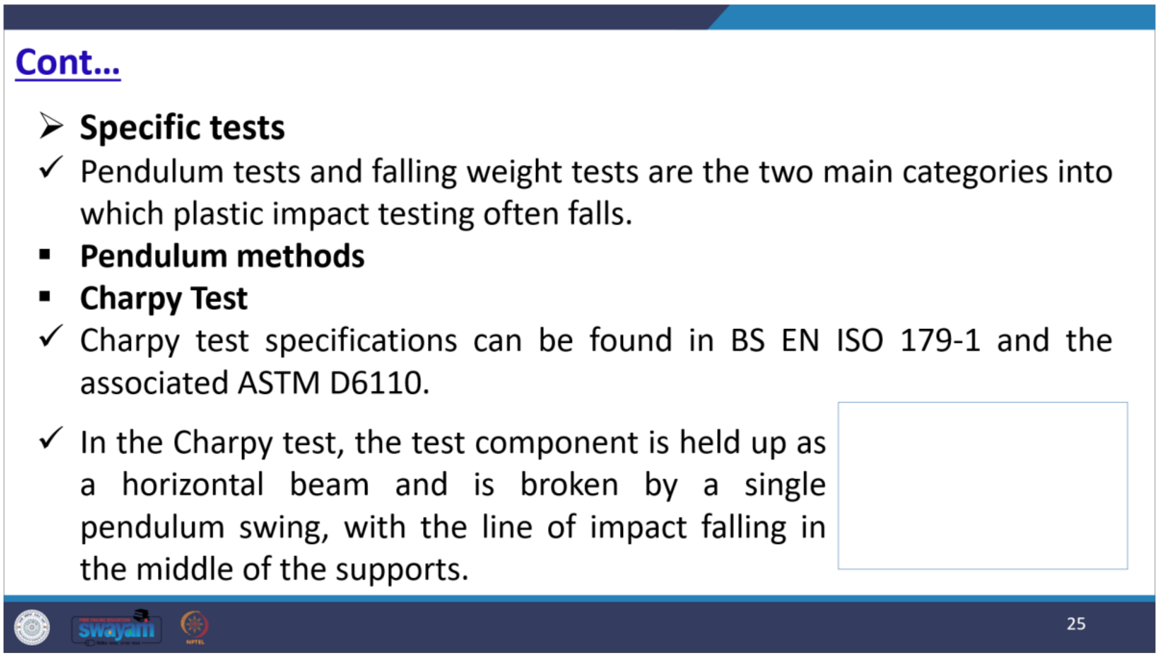
The impact behavior of a material can be compromised by improper processing conditions, preventing the achievement of its intrinsic toughness. Inadequate drying of moisture-absorbing plastics, for instance, can substantially reduce impact strength. Poor processing conditions may also lead to the formation of voids, acting as stress concentrators and compromising impact resistance. Moreover, high processing temperatures can induce thermal degradation, further diminishing impact strength.



weak weld line resulting from a poorly designed mold can significantly diminish the overall impact strength of a molded part. Test pieces extracted from compression-molded plaques typically exhibit lower impact strength compared to those directly injection molded. Additionally, test pieces with molded notches generally demonstrate higher impact strength than those with machine notches. Molecular weight and degree of crystallinity also play critical roles in determining impact resistance.

When all other factors are equal, a decrease in average molecular weight tends to decrease impact strength, while an increase enhances it. However, the effect is relatively small above a certain critical molecular weight threshold. The degree of crystallinity, particularly in semi-crystalline polymers like polyolefins, can diminish impact resistance and increase the risk of brittle failure. Therefore, the thermal history of a product significantly influences its impact behavior, with materials quenched from the melt typically exhibiting greater durability compared to those cooled slowly.

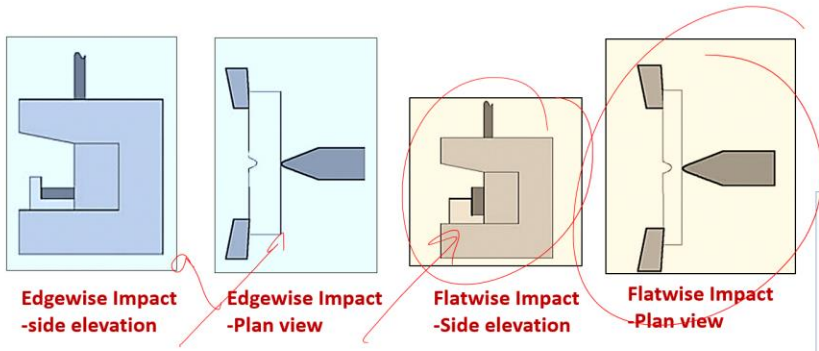
Moreover, the impact methodology employed can greatly affect impact test results. For instance, a pendulum impact test may yield different results than a falling weight test. Normalizing impact energy for a given test piece can be achieved by dividing the energy extracted from the pendulum by the cross-sectional area behind the notch. However, it's important to note that different test piece sizes may produce varied impact data, making it challenging to directly apply impact data to design estimates. Therefore, comparisons between materials should be made cautiously, ensuring that similar items are compared to avoid drawing erroneous conclusions.



In plastic impact testing, there are two main categories: pendulum methods and falling weight tests. One of the specific tests within the pendulum methods category is the Charpy test. The specifications for the Charpy test can be found in standards such as BS EN ISO 1791 and ASTM D 6110. In the Charpy test, the test component is positioned as a horizontal beam and is broken by a single pendulum swing, with the line of impact falling in the middle of the supports. Test pieces can be tested with or without notches and may be oriented either edge-wise or flat-wise.

Cont…

- ✓ Test pieces may be tested both with and without notches, and they may be orientated either edgewise or flatwise.



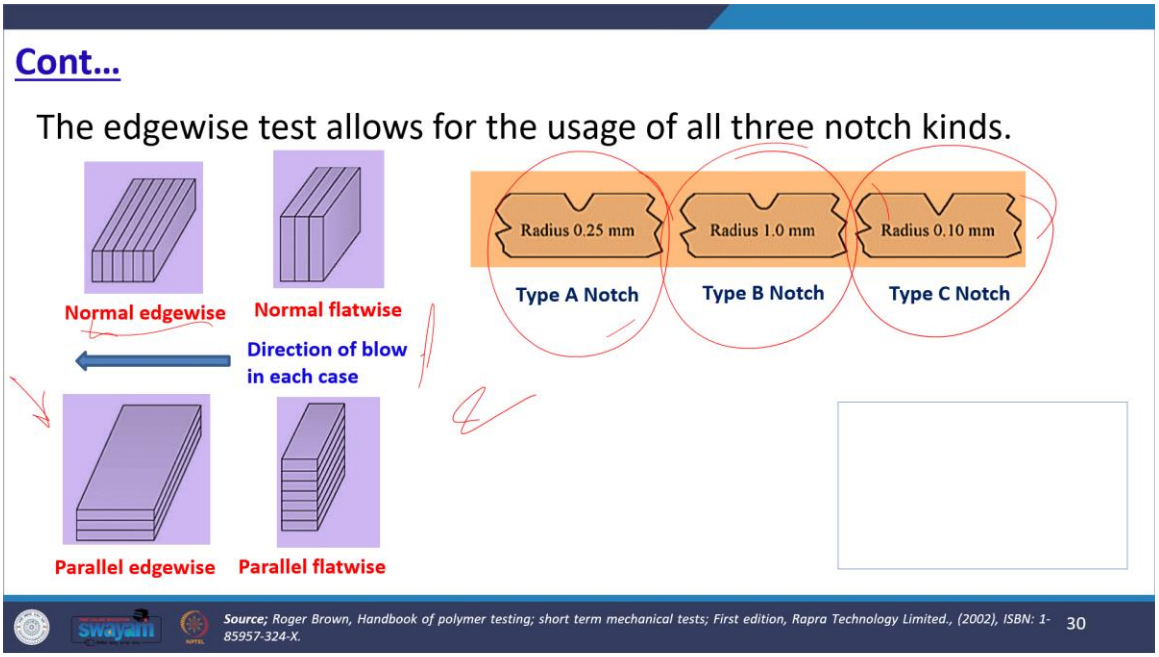
Source; Roger Brown, Handbook of polymer testing; short term mechanical tests; First edition, Rapra Technology Limited., (2002), ISBN: 1-85957-324-X.

In the edge-wise impact configuration, the test piece is oriented such that the pendulum swing occurs in the direction of the 10 mm dimension, causing bending over the surface of an 80 x 4 mm piece. On the other hand, in the flat-wise impact configuration, the pendulum swing is directed in the test piece's 4 mm dimension, resulting in bending over the surface of an 80 x 10 mm piece. The directionality of the test is best understood in reference to the actual dimensions of the test item. The center parallel section of the multifunctional test specimen can be used to cut the standard test bar, which typically measures 80 x 10 x 4 mm.

Cont…

- ✓ The test's directionality is best understood in reference to the actual dimensions of the test item.
- ✓ The center parallel section of the multifunctional test specimen can be used to cut the standard test bar, which has dimensions of 80 x 10 x 4 mm.
- ✓ In the flatwise test, the direction of the pendulum at impact is in the test piece's 4 mm direction, causing bending over the surface's 80 x 10 mm.

For most testing needs, the edge-wise test geometry is now the preferred choice. Historically, the edge-wise test was primarily used to assess how fiber reinforcement impacted impact strength, while the flat-wise test was more common. In laminated test pieces, laminations can be parallel or perpendicular to the direction of load during either flat-wise or edge-wise testing. The type A notch, with a radius of 0.25 mm at the notch base, is the most favored notch type. Additionally, there are the extremely sharp 0.1 mm type C notch and the blunt 1 mm type B notch.

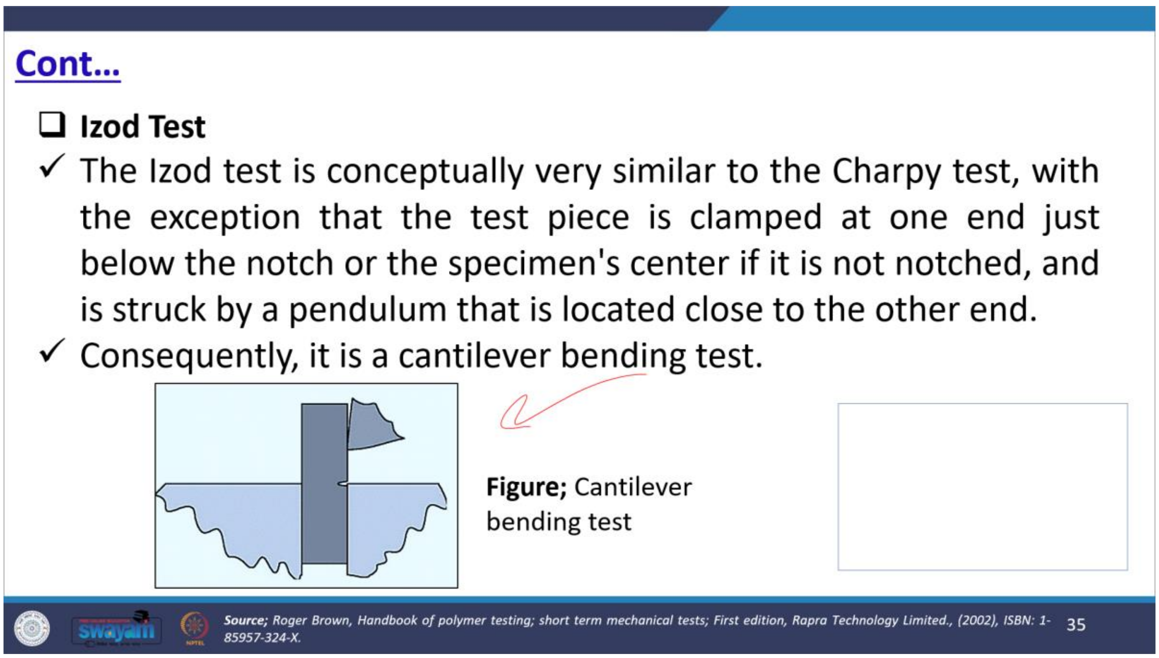


In the flat-wise test, which can also be conducted with or without notches, two notches are machined across the 4 mm direction, positioned opposite each other, resulting in a 6 mm width between the notches on the test piece. The edge-wise test allows for the use of all three types of notches. The standard test piece is suitable for general testing, but when testing sheet material, it is permissible to test the entire thickness of the sheet up to a maximum of 10.2 mm. If needed, one surface of the sheet can be cut to reduce the thickness to 10 mm.

However, thin samples are unsuitable for this test, as they may buckle when tested edge-wise or bend without breaking when tested flat-wise. Alternative geometries with no prescribed specimen sizes are permitted for long fiber-reinforced polymers. The determining factor is the span of thickness ratio (L/H ratio), with a ratio of 20 recommended for type 2 test pieces and 6 preferred for type 3 test pieces. In cases where thinner sheet material is tested, a ratio of 8 is allowed due to limitations of the testing apparatus.

For flat-wise testing, the test piece width is either 10 mm or 15 mm, with 15 mm used for larger or irregularly shaped constructions. Now, let's delve into the ISO standards. There are two pendulum lengths covered by the ISO standard, resulting in various impact velocities. The most commonly used pendulum has an impact velocity of 2.9 meters per second, with five specified pendulums covering a range of energies from 0.5 to 5 joules. The larger machine features pendulums with energies of 7.5, 15, 25, and 50 joules, with an impact velocity of 3.8 meters per second.

Regarding ASTM standards, the ASTM D6110 test is generally similar but differs in specifications. The preferred test specimen measurements are based on imperial units. However, a current standard condition error causes the figure supposed to display the dimensions of the test piece to instead illustrate the geometry of the anvil used for the micrometer. The ideal test piece is likely 127 millimeters long, 12.7 millimeters wide, and between 12.7 and 3 millimeters thick, with a distance of 95.3 millimeters between the supports, contrasting with the 62 millimeters required by ISO.



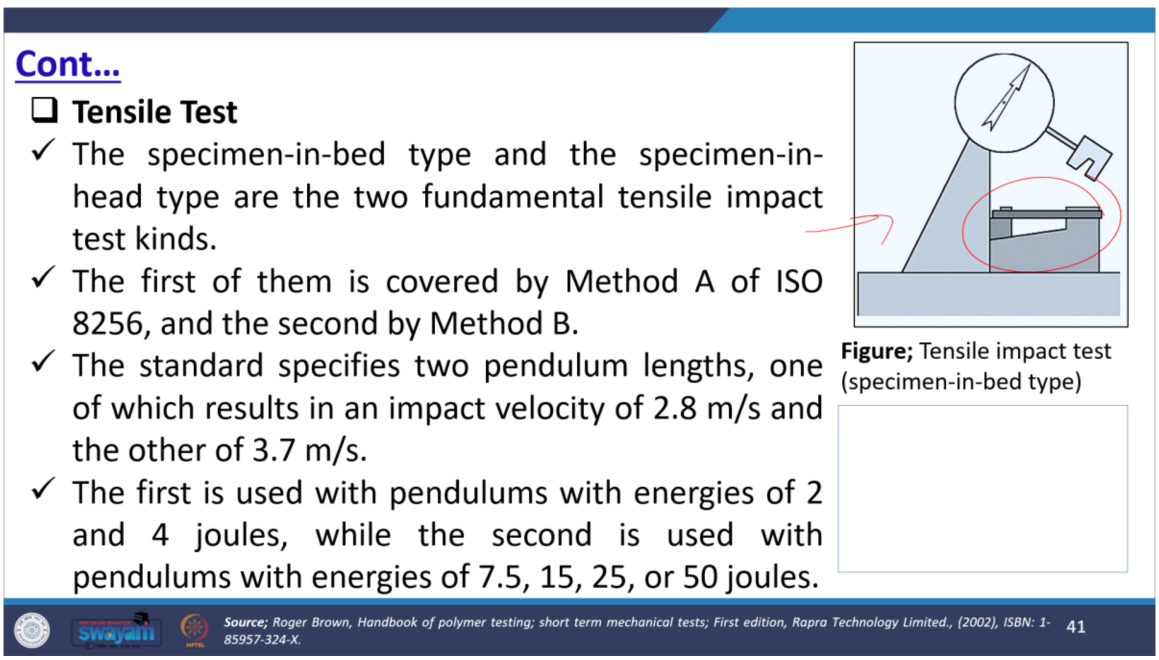
Moving on to the IZOD test, it is conceptually akin to the Charpy test, except the test piece is clamped at one end just below the notch at the specimen center. If it is not notched, then it is struck by the pendulum located near the other end, making it a cantilever bending test.

Several standards provide details for the tensile impact test, including BS European standard ISO 180 and ASTM D256, with variations in procedures C, D, and E. The widely used ISO standard test piece measures 80 by 10 by 4 millimeters and offers three permissible variations: unnotched, with a 0.25 millimeter radius notch, or with a 1.0 millimeter radius notch (type B). While laminated plastics can be tested flat-wise, the test is typically conducted edge-wise, akin to the Charpy test.

Unlike the Charpy test, the notched IZOD test can be conducted in two methods: with the notch on the same side as the point of impact or in the reverse notch test, where the unnotched phase is in tension and the notch undergoes compressive deformation. This arrangement is facilitated by striking the test piece away from the notch. Pendulums with energies ranging from 1 to 22 joules and an impact velocity of 3.5 meters per second are utilized in the IZOD test.

In ASTM standards, tests are conducted using imperial measurements, with the length of the notch as the preferred indicator of impact resistance. Method A covers materials with impact resistance exceeding 27 joules per meter, while method C adjusts for the energy needed to toss the test piece, requiring a secondary test on the broken piece. Method D estimates notch sensitivity by testing at two different notch radii, while method E, the reverse notch test, aims to simulate an unnotched test piece, although results may not be completely accurate.

Now, let's transition to the tensile test. There are two fundamental types of tensile impact tests: specimen in-bend type and specimen in-head type.



In the specimen in-bed type of tensile impact test, covered by methods A and B of ISO 8256, two pendulum lengths are specified, resulting in impact velocities of 2.8 and 3.7 meters per second, respectively. Method A utilizes pendulums with energies of 2 and 4 joules, while method B employs pendulums with energies of 7.5, 15, 25, or 50 joules.

Let's delve into method A. The test component is clamped into a suitable holder fitted onto the apparatus bed, allowing free movement of the cross head around the bed while the other end is rigidly mounted. The test piece creates a bridge between them. When the pendulum is released, it strikes the cross head arm at the bottom of its swing, transferring kinetic energy to the test piece until it ruptures. The energy received is calculated from the pendulum's height of the swing.

However, the cross head throw also consumes some energy, requiring compensation. The correction can be calculated for a specific pendulum and cross head using the equation

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

Where

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

Where,

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

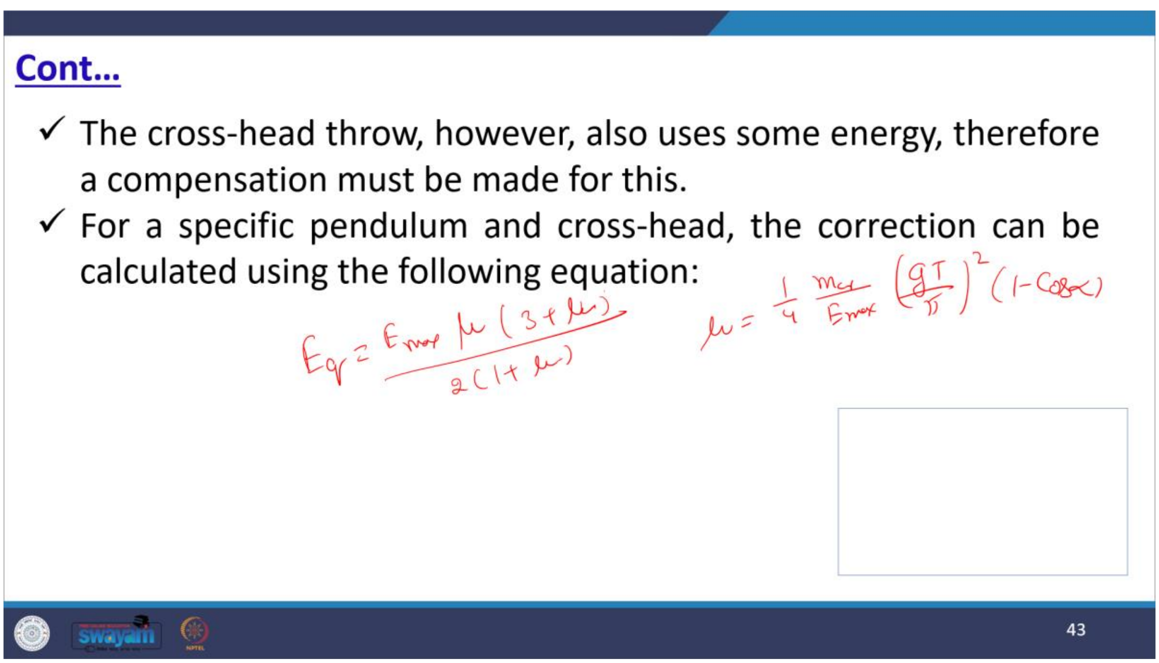
E_{max}; the maximum impact energy of the pendulum

m_{cr}; mass of crosshead

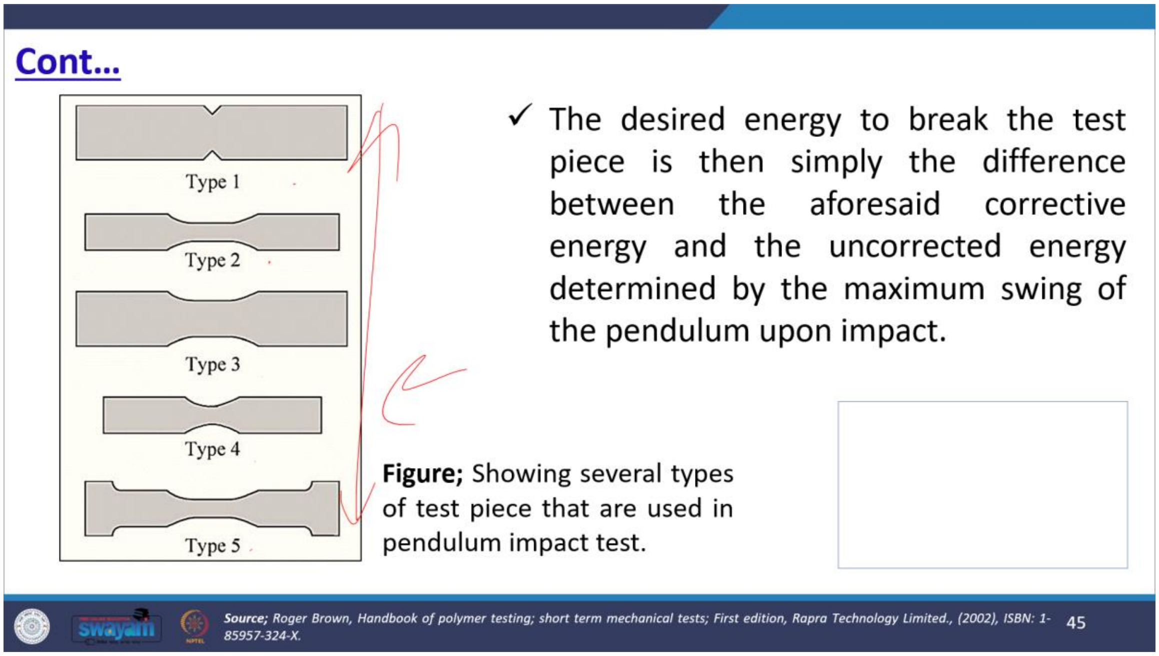
g; acceleration due to gravity

T; the period of the pendulum

$\boldsymbol{\alpha}$; angle between the positions of the maximum and minimum height of the pendulum



The desired energy to break the test piece is then obtained as the difference between the corrected energy and the uncorrected energy determined by the maximum swing of the pendulum upon impact. Various types of test pieces, including type 1, type 2, type 3, type 4, and type 5, are used in the pendulum impact test, as illustrated in the figure.



In method B of the tensile impact test, the pendulum is released from a higher position while the test item is clamped into the compound head. As the pendulum swings, its tail strikes a stiff support on the plateus frame, stopping its motion. Meanwhile, the test piece extends and ruptures as the front of the pendulum continues its swing. Unlike in method A, where adjustments are made to account for energy from the cross head bounce, in method B, adjustments are applied directly to the reading from the pendulum due to the immediate divergence of motion between the two parts of the pendulum upon contact.

The impact of molecular weight on impact and stress system properties has been explored using the tensile drop method, also known as the falling dart method. In this classic method, there are only two possible outcomes for each drop: either the test piece fails according to predetermined criteria, or it passes. Due to the large number of test specimens needed, it is impractical to determine the percentage of success or failure without statistical analysis.

Newer technologies incorporate piezoelectric or resistive transducers into the dart, allowing for direct measurement of force during impact and quantifiable results for each test piece. The BA EN 6603-1 standard outlines a general test for plastics using a dart with a 20 mm diameter striker released from a height of 1 meter onto supporting test pieces, preferably 60 mm square or round and 2 mm thick. Although the standard acknowledges that different results may arise from clamped or unclamped test pieces on the support and permits the use of a 10 mm diameter striker, it offers two chosen methods for analysis: the statistical or probit method and the staircase method.

Let's delve into the staircase method. In this method, the mass of the dart is adjusted in predetermined increments depending on whether the previously tested item passed or failed. If a test item succeeded, the mass is increased to enhance the likelihood of failure in subsequent tests. Conversely, if it failed, the mass is decreased to reduce the likelihood of failure in subsequent tests. To establish an appropriate starting mass and increment, a minimum of 20 test pieces must be produced, with an additional 10 used as preliminary specimens. Throughout the test, the increment by which the mass is adjusted must remain consistent.

Now, let's discuss the statistical or probit method. A minimum of 40 test items are required, although in practice, 60 or more are often necessary. Initially, 10 test pieces are subjected to specific conditions, and the failure rate is recorded. Subsequent adjustments are made to the mass, and another 10 tests are conducted, continuing until at least three results are achieved with failure rates greater than 0% and less than 100%, including at least one result above 50% and one below 50%. This method allows for non-uniform increments of energy application, ensuring equitable distribution of outcomes during testing. However, it is not the recommended method due to changes in impact velocity and energy.

It's worth noting that adjustments can also be made to the height instead of the mass for both test methods. For testing plastic pipes, the variable falling height method, described in BSEN 1411 and BS2782 method 1108B, is applicable. To calculate the mean impact strength and standard deviation using either the staircase method or statistical method, the percentage of passes or failures is plotted against the impact parameter (energy, mass, or height), and a best-fit straight line is determined. The parameter corresponding to a 50% failure chance represents the mean value, while the standard deviation is calculated as the difference between this parameter and the values corresponding to 16% or 84% failure probabilities.

In conclusion, in this segment, we've discussed mechanical properties and testing protocols, including the IZOD test, Charpy test, and drop test for characterizing polymeric samples. Additionally, for your convenience, we've provided a list of references for further exploration. Thank you for your attention.