INTRODUCTION

The practical toughness of injection molded polymers depends on many factors and no single test or measurement applies to all situations. Variables include the individual application, part geometry, failure mode, and success/failure criteria. Practical toughness can be described as a balance of properties that result in strong and durable parts. Predicting the practical toughness of a material based on data sheet properties requires situation specific interpretation and judgment. Some commonly used tests relate to real world practical toughness much better than others.

The Notched Izod impact test, for example, was developed to measure the impact properties of metals, which are isotropic and homogeneous materials. However, plastic materials are not isotropic, so Notched Izod values, when used in plastics design, can be very misleading. Notched Izod does not consistently predict how a plastic material will perform in a real world application. Some plastic materials are very sensitive to molding conditions, notching conditions, and even specimen thickness which can result in Notched Izod values that do not reflect their potential performance in an application. [1]

TOUGHNESS TESTS AND MATERIAL PROPERTIES

Toughness is defined as the amount of energy a material can absorb. Tests for toughness can be separated into two main types – Impact Resistance and Durability. Impact tests are typically ‘worst case’ tests indicating how much stress a part can take before ultimate failure or loss of function. Durability tests reveal fundamental intrinsic material properties that are relevant to part design and relate to how much handling and abuse a part will take without showing evidence of damage. The choice of which properties and tests to use for material comparison depends on the application and design criteria.

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	Impact Resistance	Durability
Examples of tests	Falling Dart (Instrumented, Gardner) Pendulum (Izod, Charpy)	Tensile and Flex
Usage simulated	Toughness up to failure	Normal abuse and failure point
Deformation rate	Fast	Slow
Properties measured	Extrinsic (sample dependent failure point) If notched, only crack propagation	Extrinsic (Failure) and Intrinsic (Fundamental Material Properties) Provides stiffness and strength
Relevance to performance	Falling Dart - High Pendulum - Low	High
Test method	Not time consuming	Standardized Time-consuming
Equipment	Expensive if instrumented	Expensive (Instron® Systems)

ADVANTAGES AND DISADVANTAGES OF TOUGHNESS TESTS

Pendulum Impact Tests
Examples: Notched Izod, Unnotched/Reverse Notched Izod, Charpy Impact, Tensile Impact
Description: A clamp holds one end of a notched or unnotched specimen. A pendulum with a known weight and initial height is released and swings down and through the sample. The sample absorbs energy as it bends and/or breaks, slowing the pendulum. By measuring the height the pendulum climbs to after impact, the energy absorbed by the specimen can be calculated.
Mechanics: Notched Izod/Charpy involves only crack propagation. Unnotched Izod/Charpy involves both crack initiation and propagation. Tensile Impact involves elongation at high strain rates.
Advantages: Low equipment cost; fast and easy test. Notched Izod and Charpy are commonly used for plastics especially as a QC test for material consistency.
Disadvantages: Pendulum tests do not measure a material property, only a response to one particular mode of impact (uniaxial). This provides minor relevance to real world applications especially when specimens are notched. Molding conditions can have a very large effect on measured value. Results are easily misunderstood or misinterpreted. Other impact measurements may not correlate to Notched Izod numbers; for example, some materials with high Falling Dart Impact resistance may have relatively low Notched Izod values.

Falling Dart Impact Tests (Instrumented)
Examples: Falling Dart (FDIT), Instrumented Impact (Kayness, Dynatup)
Description: High velocity ram is dropped onto a plaque of material. Pressure transducer behind tip measures stress vs. strain during impact, typically to failure. Dimensions, speed, and weight can be varied.
Mechanics: Involves crack initiation and propagation. Flexural properties are important.
Advantages: A high-speed biaxial test is relevant to real world practical toughness. A large amount of data is collected (stress-strain curves).
Disadvantages: Does not measure intrinsic material property. Tests are not standardized, so it can be difficult to compare results instrument to instrument.

Falling Dart Impact Tests (Non-Instrumented)
Examples: Gardner Impact, Ball Drop
Description: Weight dropped from different heights to determine failure point. Diameter of ball or rounded tip and support ring can vary.
Mechanics: Gardner test involves only crack initiation. Ball Drop tests may involve crack initiation and propagation and flexural properties depending on failure criteria.
Advantages: Application driven failure criteria – appearance or strength. Biaxial impact tests relate better to real world practical toughness. Low equipment cost.
Disadvantages: Subjective failure criteria (pass/fail). Not standardized (except Gardner). Can be time-consuming because a large number of samples are usually tested.

Tensile and Flexural Properties
Examples: Flex/Tensile Strength, Elongation (yield and break), Flex/Tensile Modulus
Description: Instrumented test at constant strain rate (e.g., Instron® Universal Testing System). Different clamps used for Tensile and Flexural testing.
Mechanics: Measures stress-strain behavior in flexural (bending) or tensile (elongation) mode. Tensile test includes necking of material after yield point.
Advantages: Measures fundamental material properties (stiffness/modulus, strength) which are useful for design, as well as, extrinsic material properties relating to failure mode (ductility/elongation) based on ASTM or ISO standards. A large amount of data is collected (stress-strain curves).
Disadvantages: Expensive equipment, time-consuming tests. Slow speed uniaxial test does not relate as well to some real world failure scenarios.

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MATERIAL SELECTION CONSIDERATIONS

The following are some of the key factors to consider as part of the material selection process:

- Part size and geometry (complexity, thickness, curves and radius, draft angles)
- Appearance desired (clarity, special visual effects, color consistency and stability)
- Function (toughness and rigidity required, other properties/performance characteristics)
- Failure Criteria (rate and mode of anticipated impact, acceptable wear and tear vs. loss of aesthetics or structural integrity, brittle vs. ductile failure mode)
- Molding considerations (ease of processing, process temperatures, injection pressure and press size, mold release, molded-in stress, cycle time, regrind loss/recycle)
- Environment (usage temperature, UV exposure, weathering, chemical exposure, gamma sterilization)
- Regulatory requirements (FDA, Medical, UL)

SUMMARY

How will you know if a material will work in your application? Data sheet properties are an indicator of design success that can be complemented by CAD/CAE engineering and other support tools. However, there is no substitute for testing the practical toughness of alternative materials in actual molded parts.

For more information, contact your Ineos Nova representative or visit www.styrolution.com to learn more about the practical toughness of our NAS® and ZYLAR® clear acrylic copolymers. These products are often able to meet design requirements at a lower total cost compared to other engineering resins.

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DEFINITIONS

Anisotropic Material	A material whose physical properties, such as index of refraction and compressibility, depend on the direction in which the measurement is made; for example, plastic.
Ductility	The ability of a material to be plastically deformed by elongation without rupture.
Durability	A part or structure continuing to be useful after time and usage. Relates to energy a material can absorb and release without unacceptable permanent damage.
Elastic Limit	The greatest stress a material can sustain without any permanent deformation remaining upon complete release of the stress.
Elongation	The increase in a material's length due to stress in tension. Can be reported at yield point (necking begins) or at break point (complete rupture).
Extrinsic Property	Property of a material that is sample size dependent; for example, elongation at break.
Flexural Strength	Strength of a material in bending at a defined strain.
Impact Resistance	Amount of energy a material can absorb without breaking.
Impact Test	Determination of the degree of resistance of a material to breaking by impact, under bending, tension, and torsion loads; the energy absorbed is measured in breaking the material with a single blow.
Intrinsic Property	Fundamental property of the material; not sample size dependent; for example, modulus of elasticity
Isotropic Material	A material whose properties are not dependent on the direction in which they are measured; for example, metal.
Modulus of Elasticity	Ratio of incremental stress to the corresponding incremental strain. Higher modulus indicates a stiffer material (Young's modulus, tensile modulus, E).
Strain	Change in length of an object per unit undistorted length.
Stress	The force acting across a unit area in a solid material.
Tensile Strength	The maximum stress a material subjected to a stretching load can withstand without yielding or rupturing.
Tensile Test	A test in which a specimen is subjected to increasing longitudinal pulling stress until rupture occurs.
Toughness	A property of a material capable of absorbing energy by plastic deformation; intermediate between softness and brittleness.
Ultimate Strength	The tensile stress, per unit of the original surface area, at which a body ruptures.
Weathering	Physical and chemical decomposition of a material on exposure to atmospheric agents (for example, sunlight, rain, hot/cold extremes and cycles). Can be evaluated in accelerated tests in weatherometers with periodic water spray and UV exposure.
Yield Point	The stress at which strain increases without increase in stress. Often marked by necking or drawdown in a section of the sample.

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