Determining and Comparing Material Toughness and Heat Resistance through Various Test Methods and Procedures

Thursday September 23, 2021

Presented By: Cliff Watkins & Jeremy Bland

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PT Plastics Technology

- 40-year plastics industry veteran
- Past owner of custom compounder TP Composites
- PhD Chemistry
- 14 years with PPG Fiber Glass

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- 23-year plastics industry veteran
- Pittsburg State University-Plastics
- Process Engineering Expertise
- Six Sigma Black Belt

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Thermal
Use Temperature
Min / Max Boundaries
Spike Temperature

Mechanical
Impact
Strength
Stiffness

Static & Dynamic Load
Sliding or Rotating
Snap-fit, Screw Boss, Threads

Electrical Properties
Flammability
Weatherability

Regulatory
UL,ATEX,FDA,USP Class VI,ISO 10993,EU 10/2011
Automotive Approval

Material Options
1__________
2__________
3__________

HOW TO SURVIVE THE STRUCTURAL PA66 SHORTAGE

HOW TO IMPROVE YOUR MATERIAL SELECTION PROCESS

COMPARING NYLON-POLYAMIDES, INCLUDING SPECIALTIES

SELECTING THE RIGHT RESIN TO MEET YOUR APPLICATIONS REQUIREMENTS

RESOLVING PROCESSING AND PART PERFORMANCE ISSUES BY CHANGING MATERIALS

POLYKETONE (POK) – A MATERIAL OPTION VS EXPENSIVE AND SCARCE ENGINEERING THERMOPLASTICS

Continuation of the use of ………"The PolySource Design Funnel"

The PolySource Design Funnel

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Material Options
1__________
2__________
3__________

A lot of upfront questions to generate answers…*Impact/Toughness & Thermal Resistance*

Material Toughness and Impact Performance

Material Toughness and Impact Performance

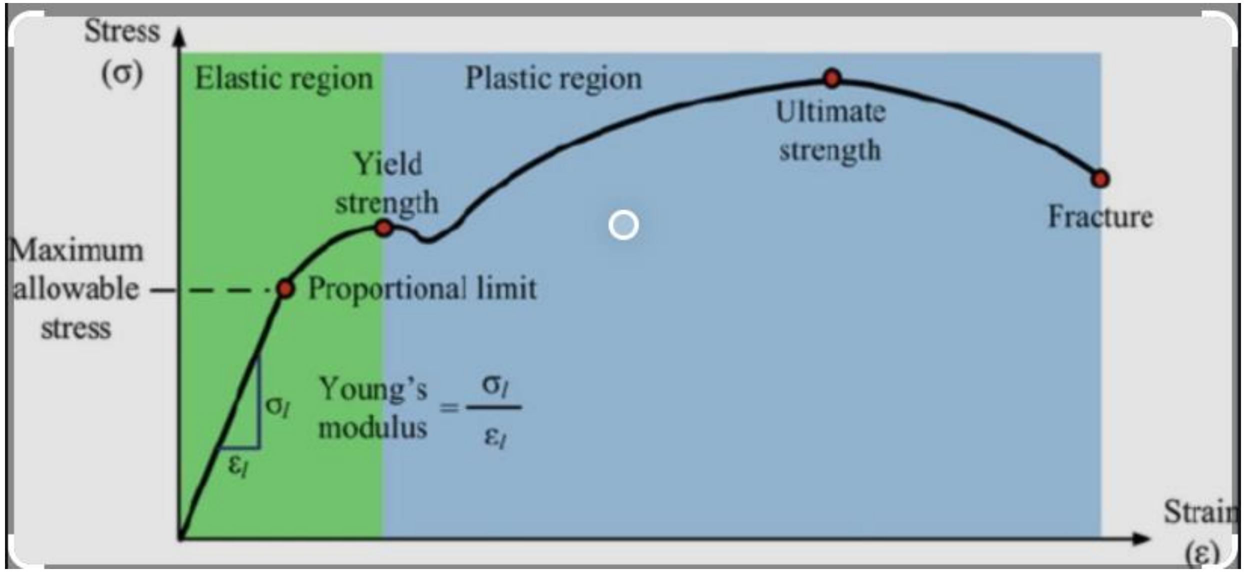
Variables To Consider In Design and Material Selection

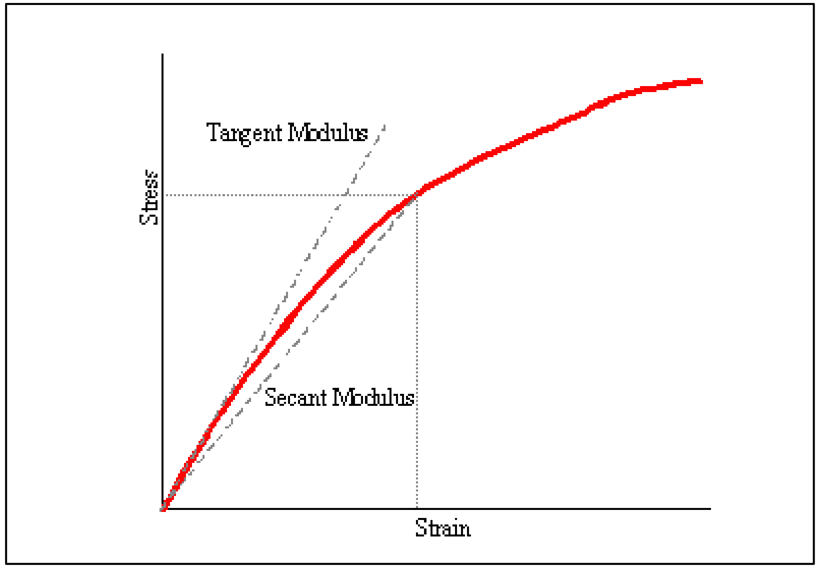
Impact and Applied Stress in Use	Cliff
Spike and Continuous Use Temperature	Jeremy
Post Mold Assembly Steps	*an upcoming webinar topic*
Chemical Exposure in Use	*an upcoming webinar topic*

In today's session, we'll discuss material impact testing and thermal performance

Material Toughness and Impact Performance

Material Toughness – "Area Under the Curve



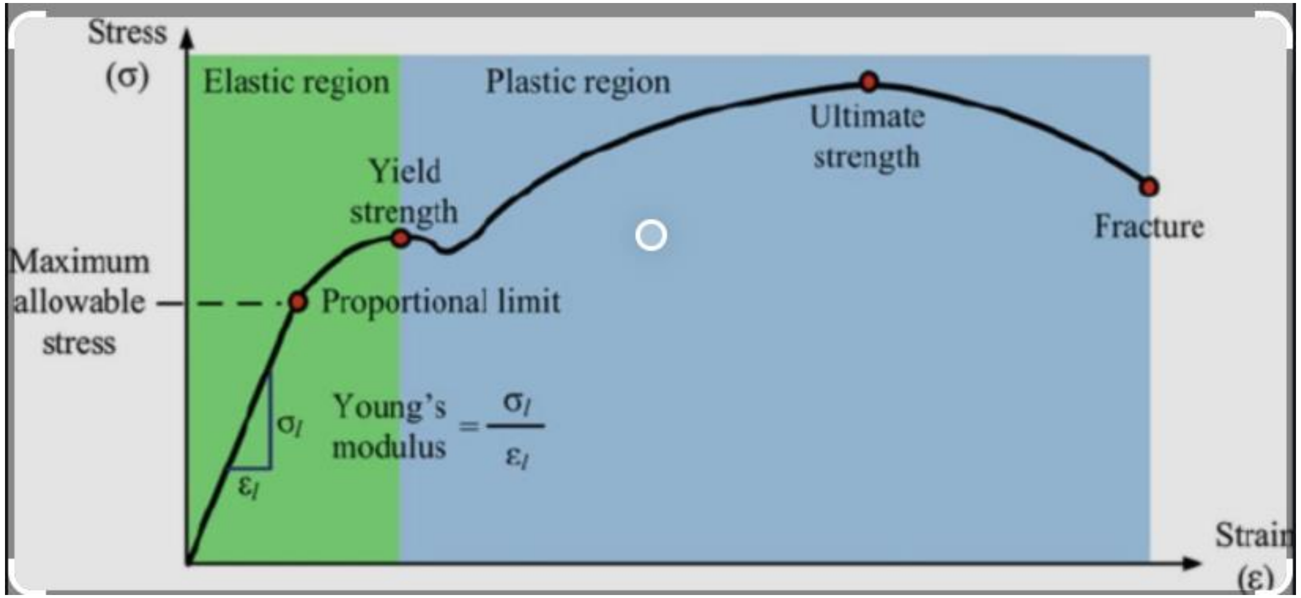


- Hooke's Law of Elasticity – stress and strain, change in a linear relationship, in the elastic region
- Young's Modulus, Tangent Modulus, Tensile Modulus and Modulus of Elasticity = stress / strain or slope of the line
- Secant Modulus is the modulus calculated at specified point on the S/S curve prior to Yield
- Past the Yield point, stress and strain are nonlinear. Stress decreases with increasing strain [the sample permanently deforms "stretches"] in the plastic region

We use modulus, stress, strain and yield often…….what are we talking about?

Material Toughness and Impact Performance

Variables that Effect Toughness/Impact Resistance

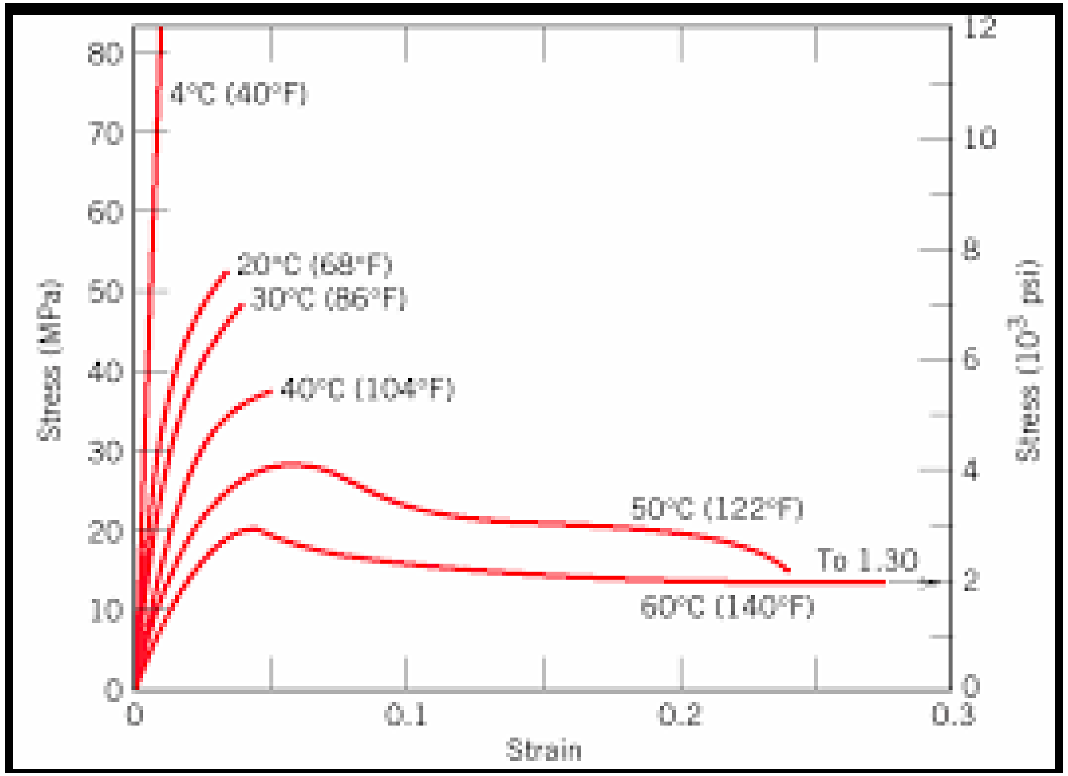


- Traditional technical datasheets fall short on providing key information for design
- Standardized ISO and ASTM test methods deliver uniformity so that materials can be compared
- ISO and ASTM test conditions though, are rarely, if ever, found in real devices

Dropping a part from 10 ft onto the floor, and Charpy impact, are like 'Apples & Oranges'

Material Toughness and Impact Performance

Temperature Effects on Toughness

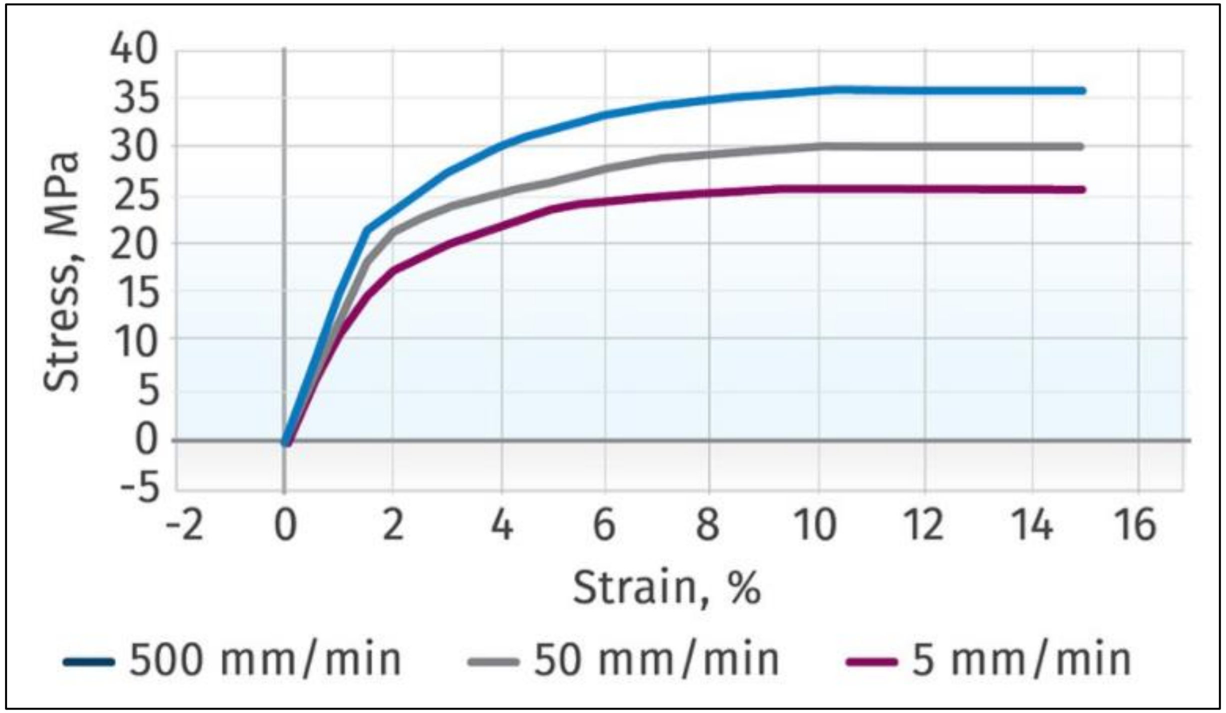


- Modulus changes, inverse to changes in temperature
- Tg of the material, additives and reinforcements all effect this response to changes in temperature
- 'Room temperature' data for a component used in an ice maker is dubious, at best

Defining the use temperature for your design is vital to selecting the 'best' material

Material Toughness and Impact Performance

Strain Rate Effects on Toughness

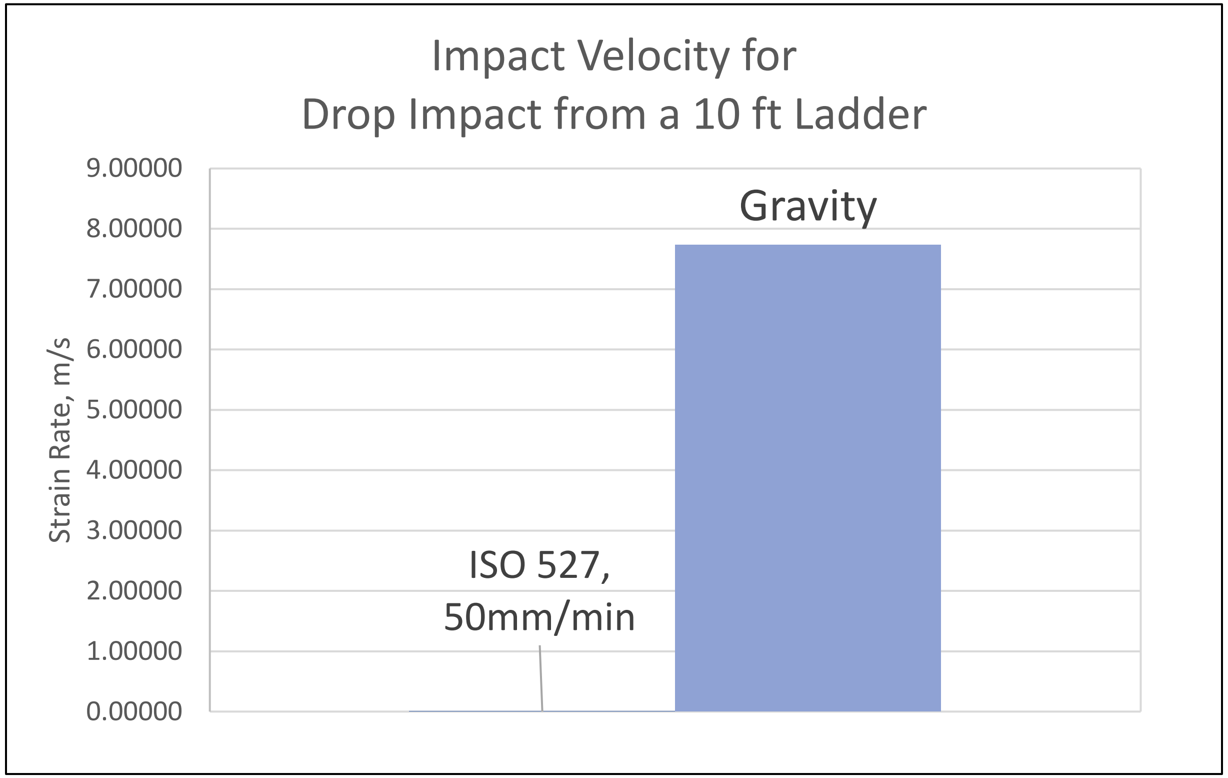


- The Elastic modulus increases with increasing strain rate and the yield point correspondingly decreases
- Yield point is "the beginning of the end"
- ISO 527 / ASTM D638 tensile tests are run at 50 mm/min or 0.00083 m/s strain rate
- Such a slow strain rate is not sufficient for real world impact or toughness decisions

Understand that a material under load will increase in modulus and will eventually deform (creep)

Material Toughness and Impact Performance

Strain Rate Effects on Toughness



- Yes, area under the curve for an ISO 527 stress/strain curve accurately describes the toughness of the material, at a strain rate of 0.00083 m/s.
- Your $500 DeWalt cordless drill hits the garage floor at 7.73 m/s falling off the ladder when you're installing a garage door opener
- While cutting a notch in a sample and hitting the sample with a pendulum is "fun", your drill still needs to be replaced
- Be aware of notch-sensitive materials, especially if you are planning to drill or machine the molded part

When drop impact is a design concern, then get data in the same strain rate domain

Material Toughness and Impact Performance

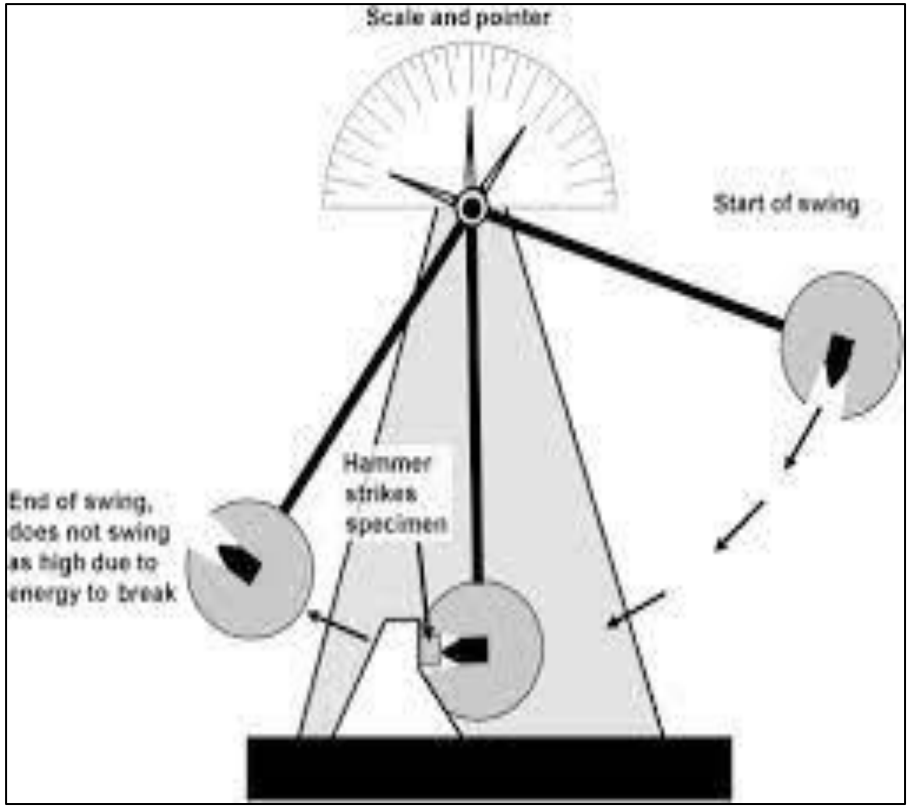
Testing Methods - Gardner Impact - ASTM D5420

- Impact Velocity from 1 m drop = 4.43 m/s
- The striking 'hammer' or tup can be varied in mass from 500 g to 5 kg
- Impact force = mass x velocity
- Manual test with high degree of subjectivity on pass/fail

This was a popular test, 30-40 years ago, and is still called out in legacy MIL specs

Material Toughness and Impact Performance

Testing Methods - Notched Izod Impact - ASTM D-256



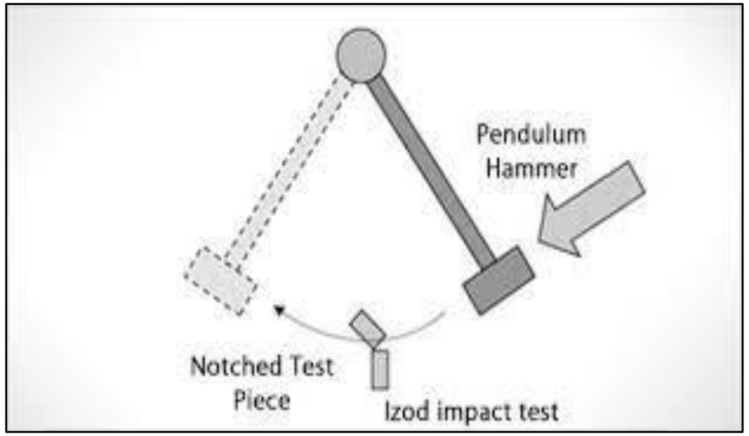
- 2-point cantilever bending / breaking test
- "Odd units" – ft-lbs./in or J/m
- ft-lbs. and Joules are units of Work
- Work per unit of thickness in front of the notch
- Milling the notch is the largest source of variation in the data
- Coefficient of Variation or % COV on N. Izod is very high
- 25% COV is not uncommon

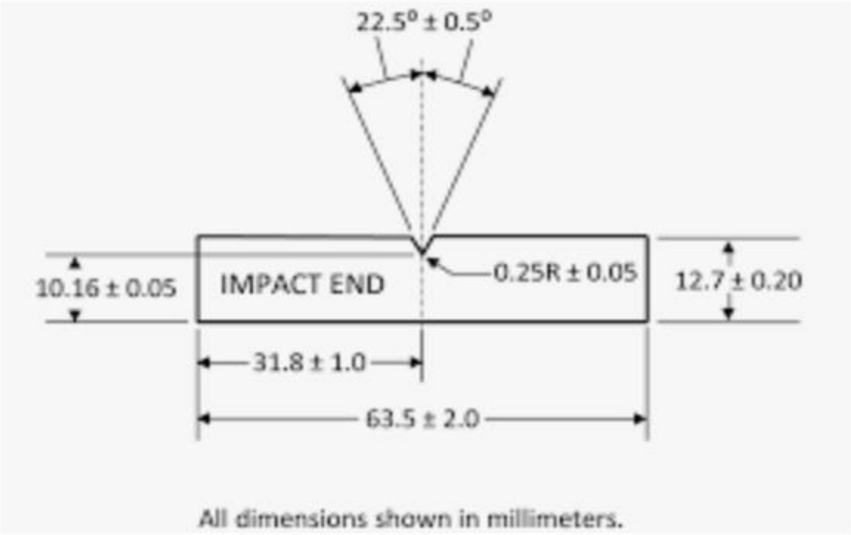
Notched Izod, ft-lbs./in			
	Mean	Std Dev	% COV
Unfilled PC	14.0	0.7	5.0%
	14.0	1.5	10.7%
	14.0	2.2	15.7%
	14.0	3.5	25.0%
30% GF PA6	2.0	0.5	25.0%

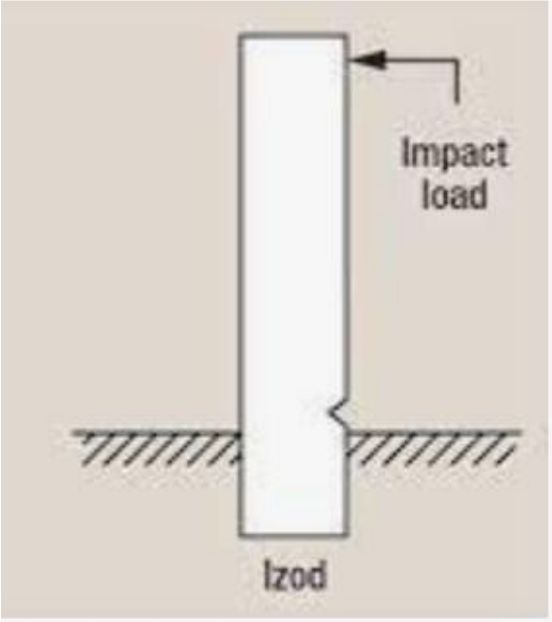
Izod is a test "everyone" accepts for reasons I can't explain!

Material Toughness and Impact Performance

Testing Methods - Notched Izod Impact - ASTM D-256







- Impact energy / sample thickness behind the notch.

Careful attention to detail preparing the sample is key.

Material Toughness and Impact Performance

Testing Methods – Notched Charpy Impact – ISO 179

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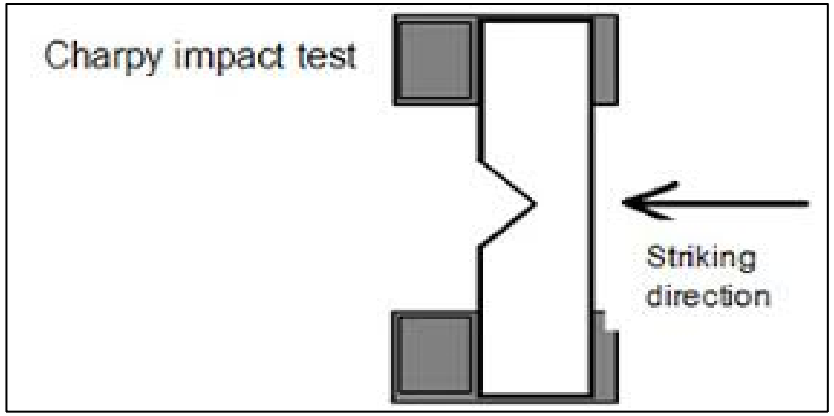
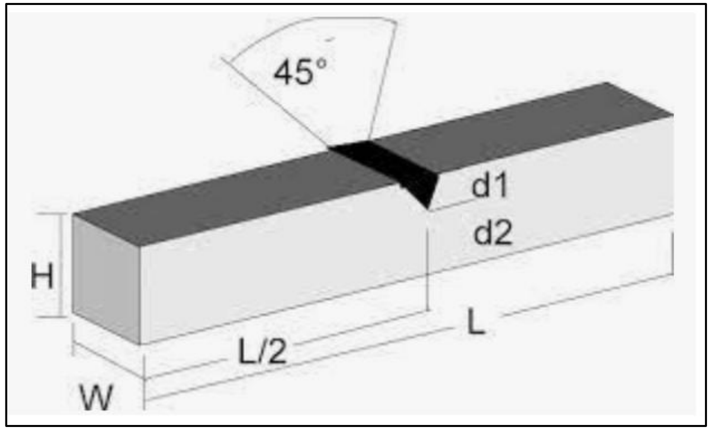




- Impact energy / cross sectional area behind the notch
- 3-point bending
- Units are kJ/m^2, or Work per unit area
- You can make an approximation to compare Notched Izod and Notch Charpy using an algorithm, but you can not actually convert ft-lbs./in to kJ/m^2.
- Concerns are the same for sample preparation, IE: machining the notch.

Careful attention to detail preparing the sample is key.

Material Toughness and Impact Performance

Typical Data Sheet Impact Values

Impact	Nominal Value Unit	Test Method
Charpy Notched Impact Strength [5]		ISO 179/1eA
-30°C	12 kJ/m^2	
23°C	65 kJ/m^2	
Charpy Unnotched Impact Strength [5]		ISO 179/1eU
-30°C	No Break	
23°C	No Break	
Notched Izod Impact		
23°C	690 J/m	ASTM D256
-30°C [6]	11 kJ/m^2	ISO 180/1A
23°C [6]	65 kJ/m^2	ISO 180/1A
Unnotched Izod Impact		
23°C	3200 J/m	ASTM D4812
-30°C [6]	No Break	ISO 180/1U
23°C [6]	No Break	ISO 180/1U
Instrumented Dart Impact		ASTM D3763
23°C, Energy at Peak	62.0 J	
Gardner Impact (23°C)	169 J	ASTM D3029
Tensile Impact Strength [7]	546 kJ/m^2	ASTM D1822

Understanding traditional data sheet values of different test conditions

Material Toughness and Impact Performance

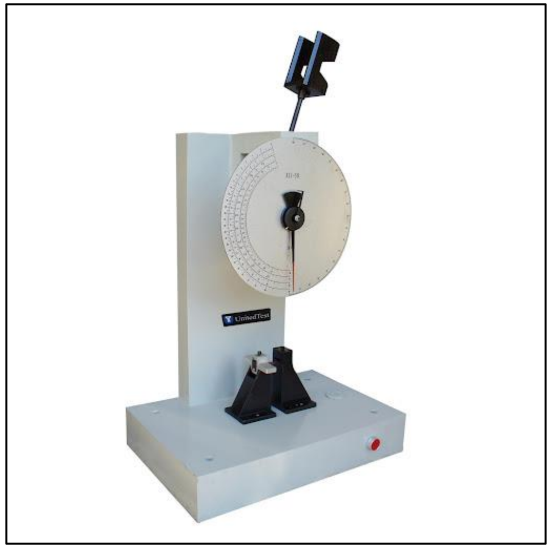
Unit Conversion

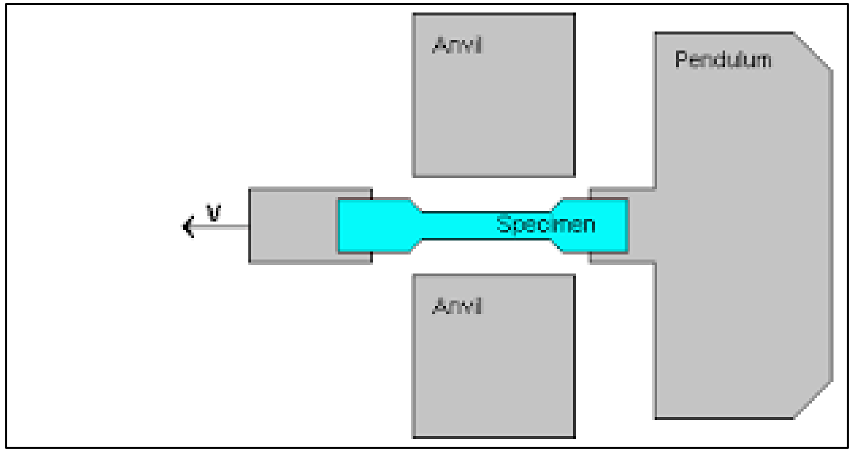
Concerning Unit Conversion !!

And yet Americans refuse to accept the metric system….☺

Material Toughness and Impact Performance

Testing Methods – Tensile Impact ASTM D1822/ISO 1856





- Tensile impact is not actually an impact test, it is a high strain rate, tensile stress test
- The data output is an analog recorder which measures the breaking force delivered by the pendulum
- At one time, UL RTI impact ratings were measured with D1822. Notched Charpy is now also used at UL

An older style test, but data collection is less then optimal

Material Toughness and Impact Performance

Testing Methods – Tensile Impact ASTM D1822/ISO 1856

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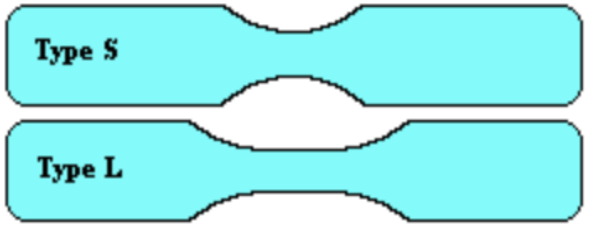
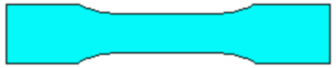


Tensile Impact Specimens

Specimen Type	Diagram
1	
2	
3	
4	
5	

- Two sample options for D1822
- Five options for ISO 1856
- A limitation these days, is access to injection molds with any of the 7 sample geometries

Many different test specimen geometries for a variety materials

Material Toughness and Impact Performance

Testing Methods – Multi Axial Drop Impact (Dynatup) ASTM D8250

- Impact velocity or strain rate, is tunable between 1 and 13 m/s
- Test temperature can be controlled between -40 and 100 ^{o}C
- The data output is exceptional with the load cells in the striking tup

	Max. Load	Energy to Max Load	Deflection @Max Load	Total Energy	Failure Type
Units	kN	Joules	mm	Joules	

For drop impact and high strain rate applications, Instrumented Impact is an excellent tool

Material Toughness and Impact Performance

Testing Methods – Multi Axial Drop Impact (Dynatup) ASTM D8250

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Customer Case Study:

- Identify an easier to mold material than the incumbent, without sacrificing drop impact

Challenges

- Datasheet information was lacking
- MFI is not reliable for mold filling because the shear rate is too low
- The molded part is tested by dropping on the shop floor from a 6 ft utility ladder

The customer was adamant that Notched Izod was not helpful, based on the 20 samples they had already tested with higher Izod values

Material Toughness and Impact Performance

Dynatup Drop Impact Yields More and Better Data

	Tensile Modulus	Tensile Stress, Yield	Tensile Strain, Yield	Tensile Strain, Break	Flexural Modulus	Notched Izod	Melt Flow Rate
units	MPa	MPa	%	%	MPa	J/m	g/10min, 300 °C, 1.2 Kg
Candidate 1	---	62	7	90	2,240	640	10
Candidate 2	---	61	---	---	2,450	637	25*
Candidate 3	---	62	---	100	2,303	747	15
Candidate 4	---	58	---	130	2,100	700	8
							*240 °C, 5Kg

Customer Case Study:

- Identify an easier to mold material than the incumbent, without sacrificing drop impact

For drop impact and high strain rate applications, Instrumented Impact is an excellent tool

Material Toughness and Impact Performance

Standard Data Sheet Properties Comparison

	Max. Load	Energy to Max Load	Defl. At Max Load	Total Energy	Failure Type
units	kN	Joules	mm	Joules	
Candidate 1	5.65	52.42	19.00	54.16	ductile
Candidate 2	4.61	47.83	18.90	50.18	ductile
Candidate 3	5.47	49.98	18.50	51.56	ductile
Candidate 4	5.16	50.68	19.37	52.92	ductile

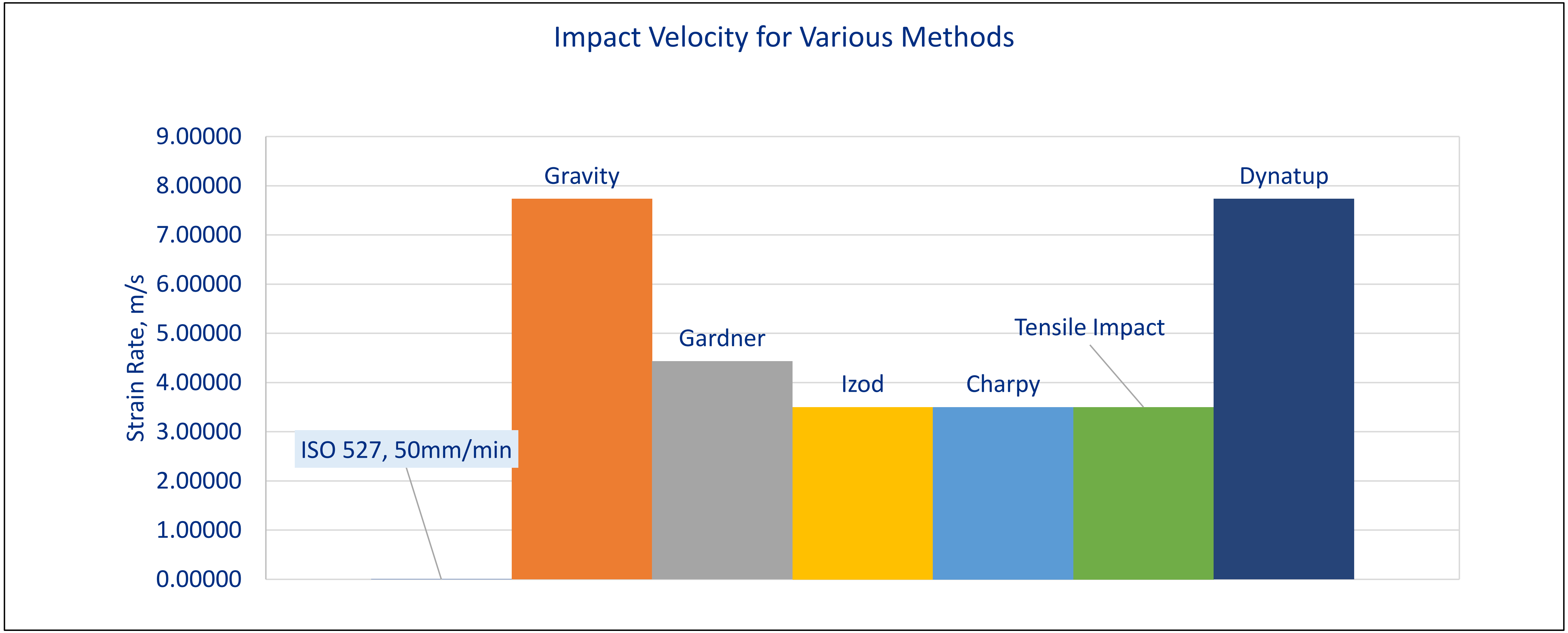
Customer Case Study:

- Identify an easier to mold material than the incumbent, without sacrificing drop impact

For drop impact and high strain rate applications, Instrumented Impact is an excellent tool

Material Toughness and Impact Performance

Strain Rate for Various 'WORKHOUSE' Test Methods



Standard technical datasheets rarely have enough information for designing with plastics

Material Toughness and Impact Performance

Things to Consider when Designing for Toughness

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Impact and Applied Stress in Use:

- Strain rate and the relationship with Key Performance Tests (KPT’s)
- Understanding and allowing for, the strong influence of use temperature on toughness
- Comparing Notched Izod or Notched Charpy values between candidates is fun, but not always meaningful
- Technical datasheets present uniform data, collected at low strain rates
- With better data, you will achieve better designs.

Ask PolySource, We’re The Fixers!

Thermal Properties

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Physical

Dimensional Stability
Flatness & Warp
Color & Appearance

Chemical

Exposed to Chemicals
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UL,ATEX,FDA,USP Class VI,ISO 10993,EU 10/2011
Automotive Approval

Material Options

1__________
2__________
3__________

A lot of upfront questions to generate answers- *Thermal Resistance*

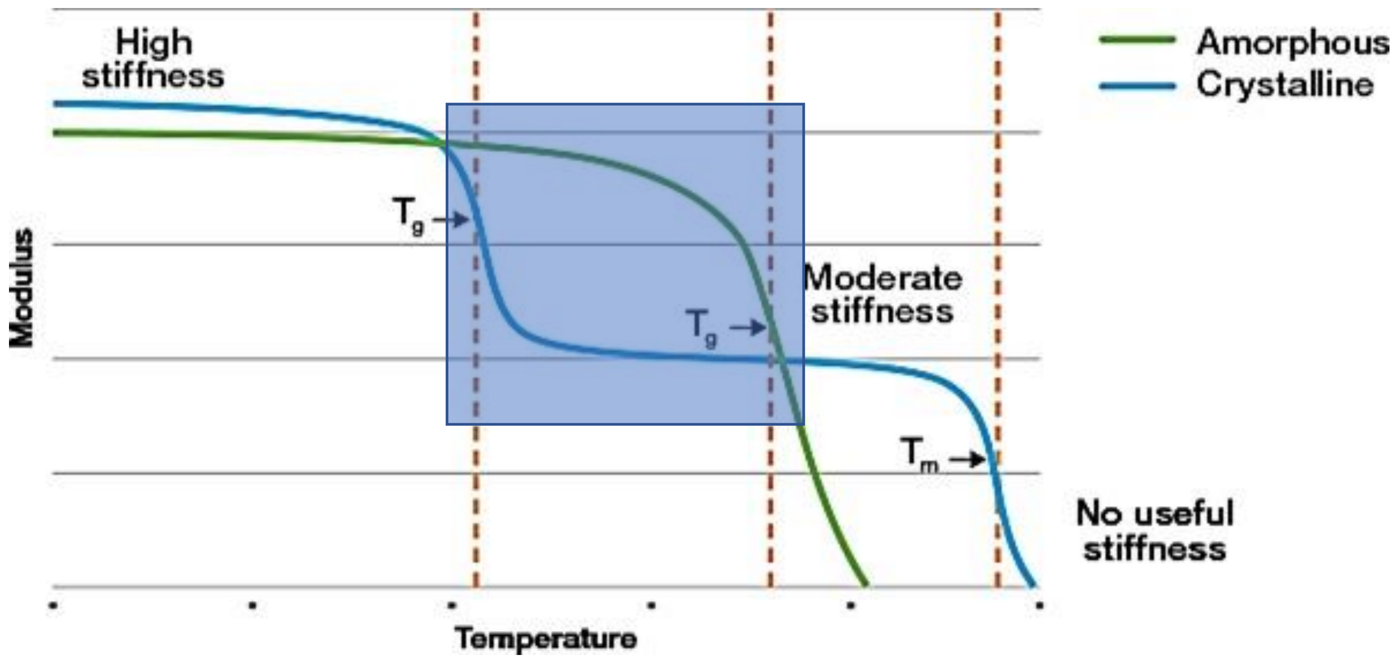
Thermal Properties

- Importance of Thermal Behavior
  - Crystalline vs. Amorphous
  - Stress-Strain curves at various temperatures

- Short Term & Long-Term tests for heat resistance
  - Heat Deflection Temperature
  - Vicat Softening Point
  - Relative Thermal Index

Thermal Properties

Semi-Crystalline VS Amorphous

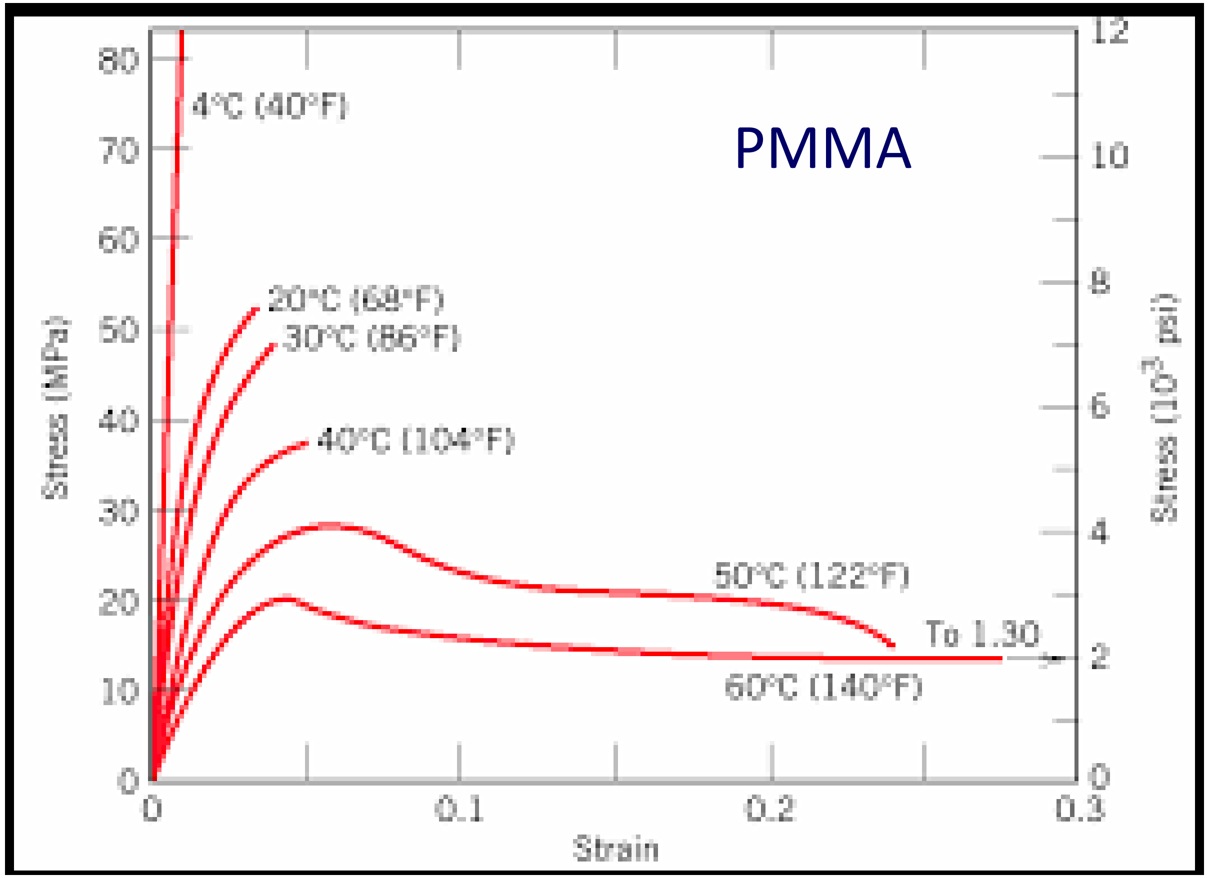


- Amorphous (PC, ABS, PS, most Polyesters)
  - Must be used below their Tg due to the severe decrease in mechanicals above the glass transition temperature (Tg)
- Semi-Crystalline (HDPE, PP, Nylons, PBT)
  - Can be used below or above it's Tg depending on applications requirements
  - Sharp melting point (Tm) where mechanical integrity fails.

End use temperature conditions will drive the selection of an amorphous or a semi crystalline material

Thermal Properties

Thermal Behavior of Plastics



- Mechanical performance depends on environmental temperatures your part is exposed to.
  - Lower temperature = lower overall strength/toughness

Understanding use temperature is vital to material selection

Thermal Properties

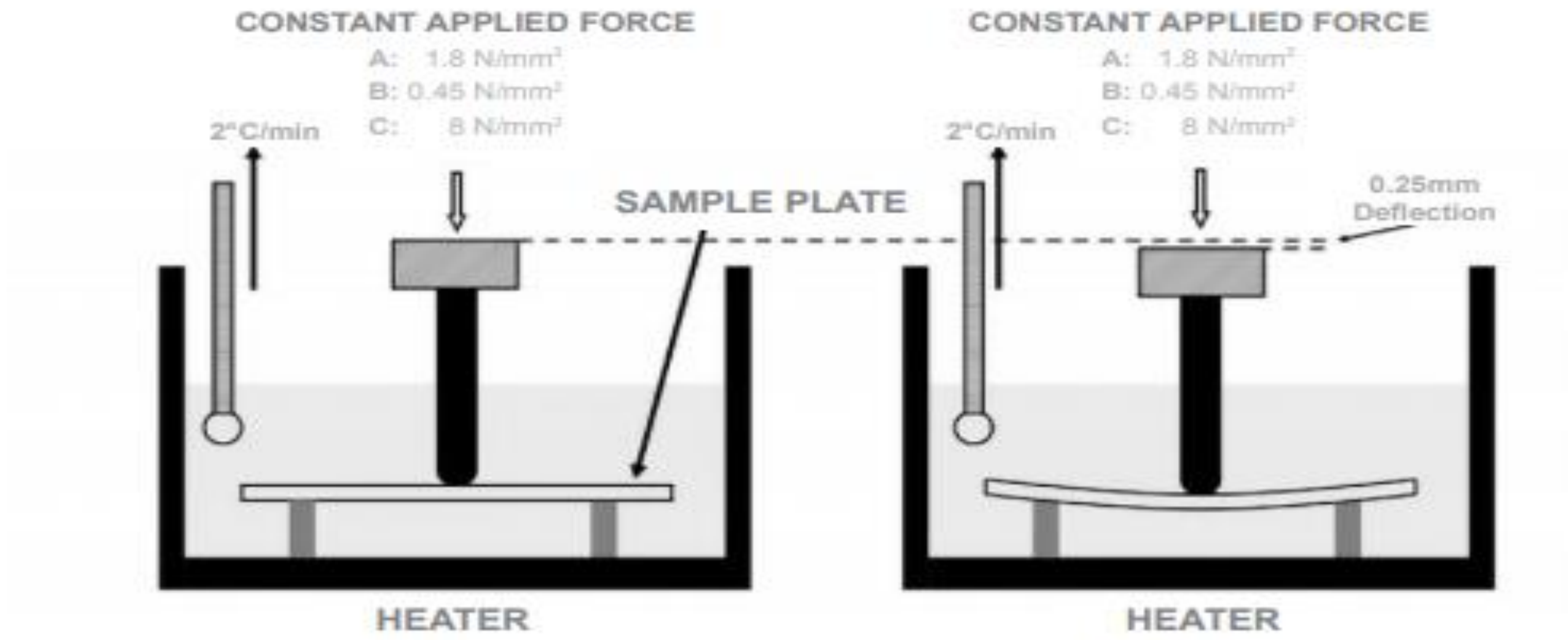
Typical Data Sheet Thermal Values

Thermal	Nominal Value Unit	Test Method
Deflection Temperature Under Load		ASTM D648
0.45 MPa, Unannealed, 6.40 mm	137 °C	
1.8 MPa, Unannealed, 6.40 mm	129 °C	
Vicat Softening Temperature	154 °C	ASTM D1525 [8]
CLTE - Flow (-40 to 95°C)	6.8E-5 cm/cm/°C	ASTM E831
Specific Heat	1250 J/kg/°C	ASTM C351
Thermal Conductivity	0.25 W/m/K	ASTM C177
RTI Elec	130 °C	UL 746B
RTI Imp	130 °C	UL 746B
RTI Str	130 °C	UL 746B

Understanding traditional data sheet values of different test conditions

Thermal Properties

Heat Deflection Temperature (HDT)– ASTM D648



HDT is an indication of short-term heat exposure VS deformation under load

Thermal Properties

<u>*Heat Deflection Temperature (HDT)– ASTM D648*</u>

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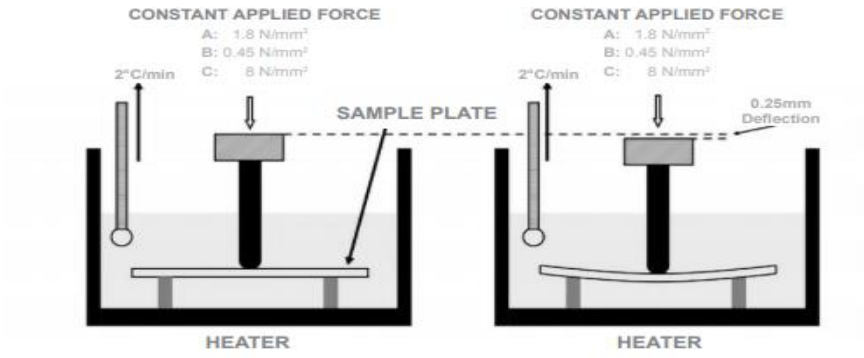
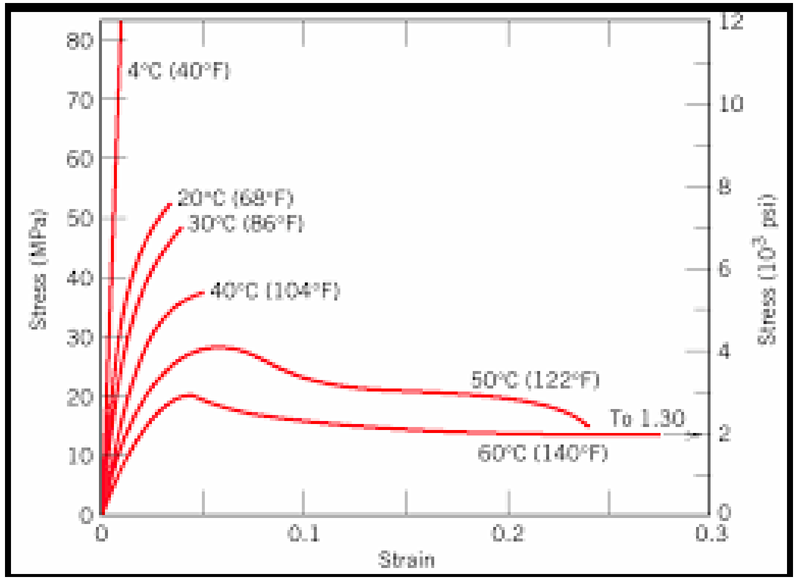




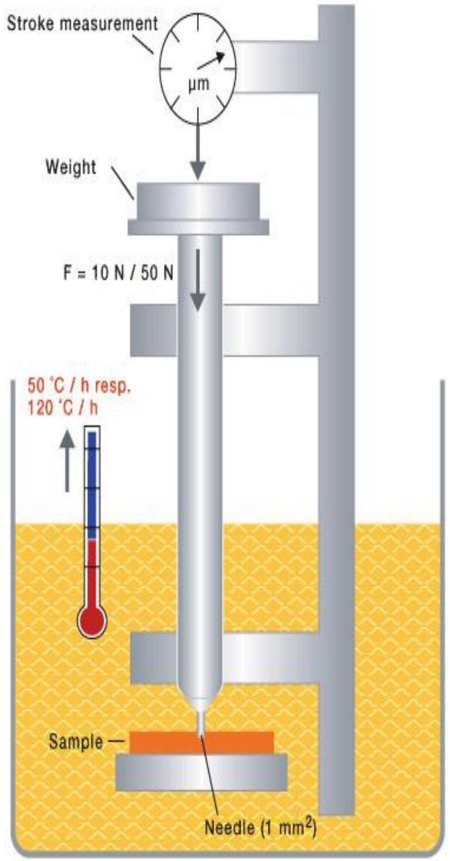
- When to use?
  - Reference value when interested in stiffness change of a polymer under load at elevated temperature.
  - <u>Short term</u> heat exposure such as max spike temp while under low load (66 psi and 264 psi).
    - Exposure time should be seconds to minutes only as this is a time dependent test.
  - Optimizing injection molding cycle time by measuring part temperature.

HDT is an indication of <u>short-term</u> heat exposure VS deformation under load

Thermal Properties

Vicat Softening Temperature – ASTM – D1525

1 mm depth



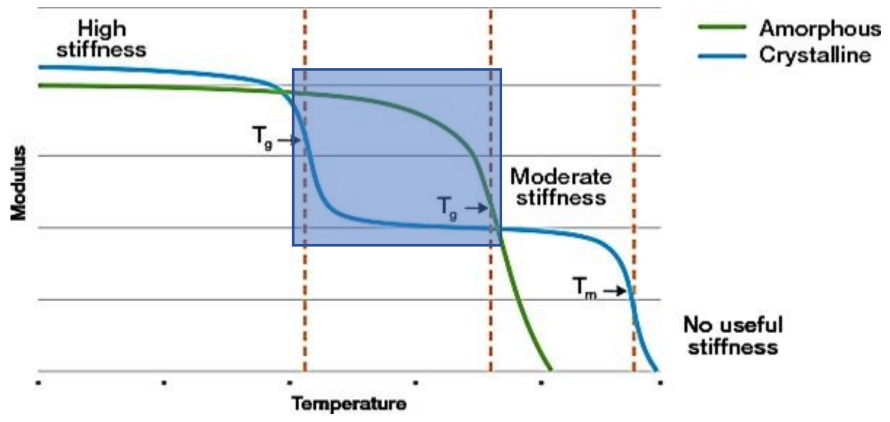
- ***When to use?***
  - Application has no load bearing on the part
  - Determine dimensional stability as a function of temperature.
    - Also, a short-term value for exposure times of seconds to minutes.

Vicat is an indication of short-term heat exposure VS deformation with 'NO' load

Thermal Properties

Short Term Temperature Resistance to Various Polymers

	Glass Transition Tg (F)	HDT @ 66psi/264psi (F)	Vicat (F)
• PC	302	277 / 255	310
• HIPS	180	192 / 178	215
• ABS	220	201 / 176	210
• PMMA	194	185 / 178	221
• PS	212	192 / 180	205
• PEI	419	405 / 374	412
• HDPE	-100	163 / NA	260
• PP	-10	200 / 120	310
• PBT	140	239 / 122	347
• POM	-58	316 / 214	324
• Nylon 6	140	338 / 140	374
• Nylon 6/6	131	374 / 158	464



Addition of reinforcements such as glass can greatly improve HDT values

Thermal Properties

Relative Thermal Index (RTI) – UL 746B

- Relative Thermal Index (RTI)
  - Hot air aging of tensile bars
  - Load free state
  - 3-4 time/temperature profiles selected based on material type
  - Property loss of 50% of the initial value
  - Data is plotted in a regression curve to extrapolate out to 100,000 hours and the corresponding temperature

Commonly used in electrical/electronic markets via UL Yellow Card

Thermal Properties

Long Term Heat Resistance (RTI) – UL 746B

Example of UL Yellow Card

Component - Plastics
File Number: E41938

Thermal	Value	Test Method
RTI Elec		UL 746B
0.71 mm	130 °C	
1.5 mm	130 °C	
3.0 mm	130 °C	
6.0 mm	130 °C	
RTI Imp		UL 746B
0.71 mm	75.0 °C	
1.5 mm	75.0 °C	
3.0 mm	75.0 °C	
6.0 mm	75.0 °C	
RTI Str		UL 746B
0.71 mm	85.0 °C	
1.5 mm	85.0 °C	
3.0 mm	85.0 °C	
6.0 mm	85.0 °C	
Ball Pressure Test (240°C)	Pass	IEC 60695-10-2

RTI value is the extrapolated temperature at which 50% property degradation occurs at 100,000 hours (~11 years)

Thermal Properties

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Long Term Heat Resistance

Relative Thermal Index (RTI) – UL 746B

- When to use?
  - Comparing two materials with similar mechanical properties to determine best fit in high temperature applications (Reinforcements do not always increase RTI)
  - Application has no load bearing on the part
  - Property loss of 50% is acceptable

- Ford Motor Company
  - Long term heat aging at multiple temps
  - 75% retention of initial properties
  - Regression curve extrapolated to a temp at 9000 hours.

Long term heat resistance relates directly to planned lifetime of part

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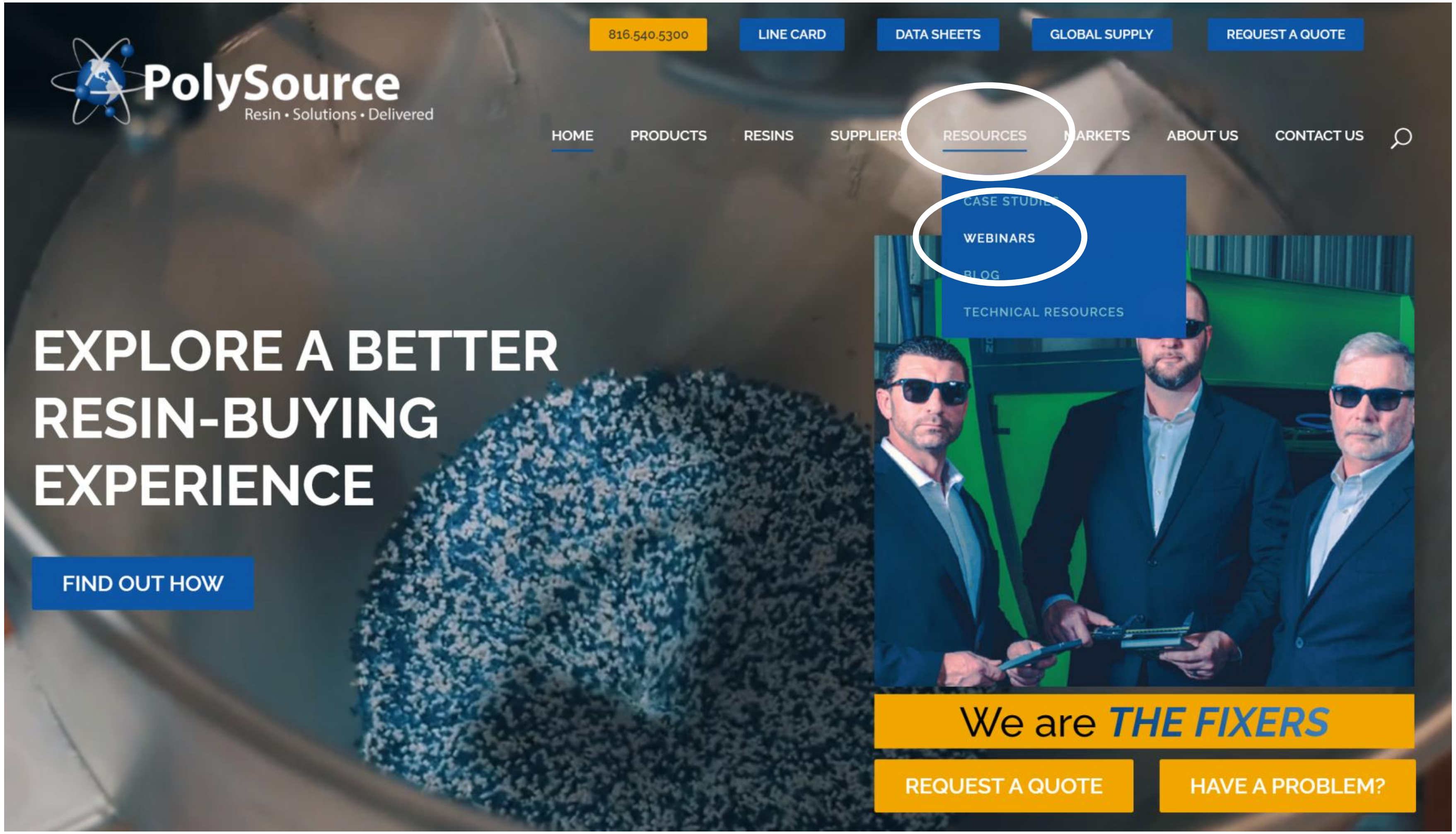
Electrical Properties
Flammability
Weatherability

Regulatory
UL,ATEX,FDA,USP Class VI,ISO 10993,EU 10/2011
Automotive Approval

Material Options
1__________
2__________
3__________

A lot of upfront questions to generate answers… That lead to the best material options

Today's Webinar



Please find the presentation @www.polysource.net/resources/webinars

Plastics Technology

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Thank You for Joining the Discussion Today!!

- 39-year plastics industry veteran
- Past owner of TP Composites-bought by Techmer PM in 2013
- PhD Chemistry
- 14 years with PPG Glass

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- 22-year plastics industry veteran
- Pittsburg State University-Plastics
- Process Engineering Expertise
- Six Sigma Black Belt

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QUESTIONS????