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Metal to Plastic

Converting challenging metal applications to plastic

Bill McMaster – Application Development Engineer, Performance Materials, BASF

Outline

Why convert to plastics?

Basic material properties / material selection

Basic thermoplastic design

Designing with structural ribs

GF resins / fiber orientation / CAE examples

Long-term properties / gating

Covered in this section

Why convert to plastics?

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Why convert to plastic?

- **Cost reduction**
  - Lower price for consumer, increased margin / volume for OEM
- **Weight reduction**
  - Key requirement for automotive, hand power tools and other industries
- **Improved chemical / corrosion resistance**
  - Eliminates the possibility of rust and the need for painting
- **Improved aesthetics**
  - Allows for molded-in-color
- **Part consolidation**
  - Reduce assembly time and cost

Why convert to plastic – Benefits of plastics over metals

- **Greater design flexibility**
  - Combine parts, color-code key parts, add textures, etc.
- **Increased tool life**
  - Up to 6 times longer tool life over die cast
- **Increased strength to weight ratio**
  - Lower density allows part to be designed with increased part strength
- **Reduced secondary operations**
  - No need for deburring, polishing, etc.
- **Warmer to the touch**
  - Reduced thermal conductivity allows part to feel “warm”

Covered in this section

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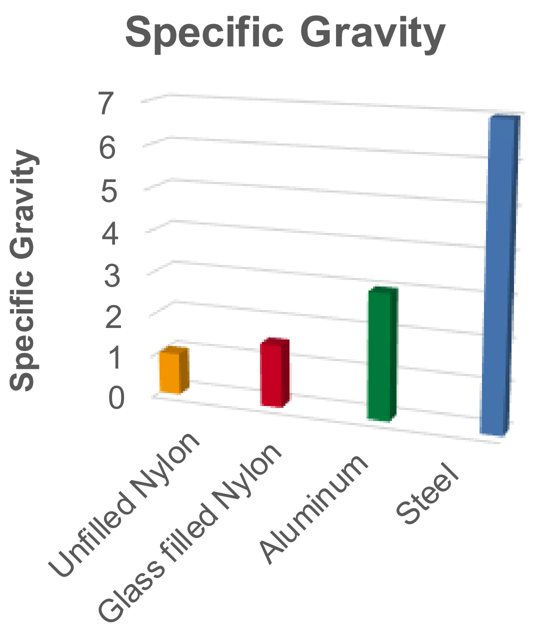
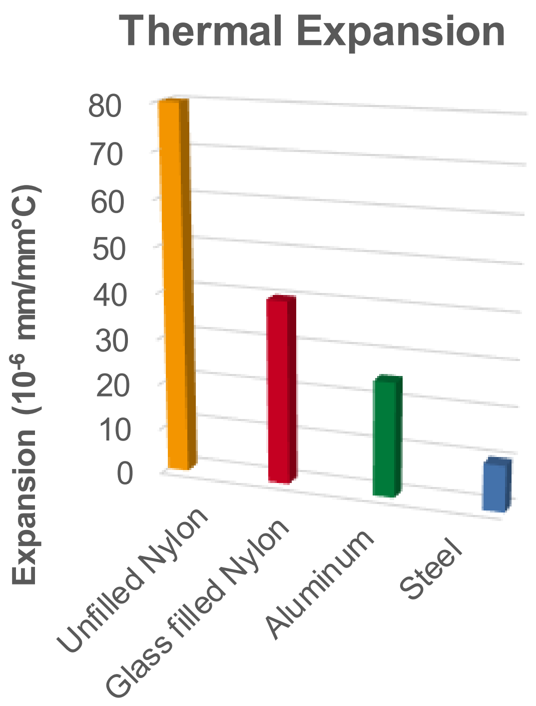
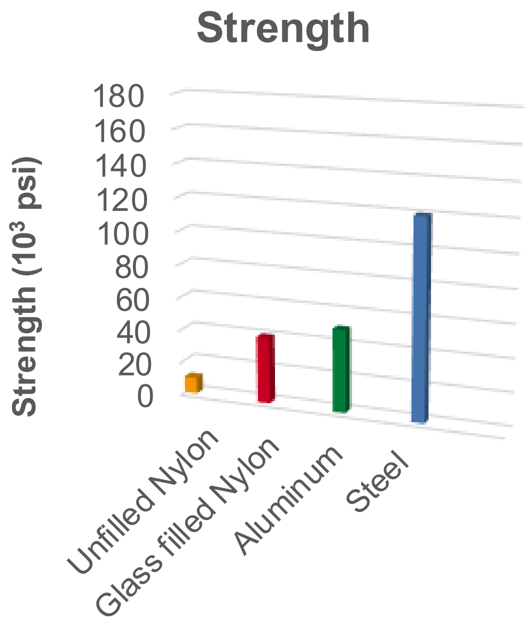
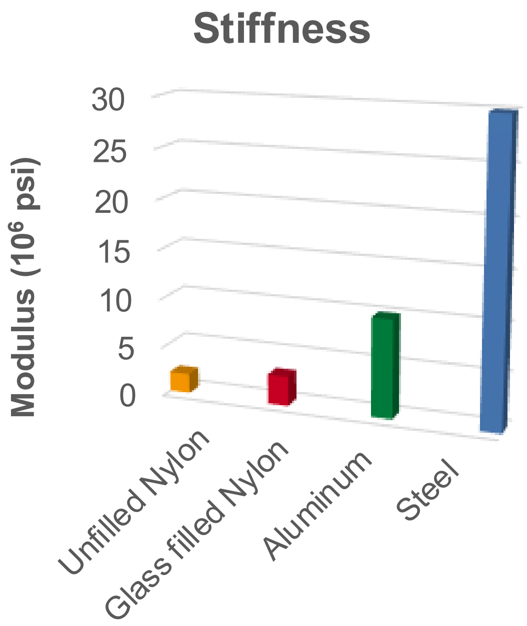
Basic material properties – Comparison









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Material selection – BASF Ultramid® B3WG6 datasheet

Product Description			
	Ultramid B3WG6 is a 30% glass fiber reinforced, heat stabilized injection molding PA6 grade.		
Applications			
	Typical applications include automotive manifolds and pedals.		
PHYSICAL	**ISO Test Method**	**Property Value**	
Density, g/cm³	1183	1.36	
Moisture, %	62		
(50% RH)		2.1	
(Saturation)		6.6	
RHEOLOGICAL	**ISO Test Method**	**Dry**	**Conditioned**
Melt Volume Rate (275 C/5 Kg), cc/10min.	1133	50	-
MECHANICAL	**ISO Test Method**	**Dry**	**Conditioned**
Tensile Modulus, MPa	527		
23C		9,500	6,200
Tensile stress at break, MPa	527		
23C		185	115
Tensile strain at break, %	527		
-40C		4.0	-
23C		3.5	8.0
Flexural Strength, MPa	178		
23C		270	180
Flexural Modulus, MPa	178		
23C		8,600	5,000
IMPACT	**ISO Test Method**	**Dry**	**Conditioned**
Izod Notched Impact, kJ/m²	180		
23C		15	20
Charpy Notched, kJ/m²	179		
-30C		11	-
23C		15	30
Charpy Unnotched, kJ/m²	179		
-30C		80	-
23C		95	110

Good for initial material screening but rarely used in design

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Functional considerations – Critical to material selection

Impact

Loads

CLTE

Mating Components

Life Cycle Requirement

Wear & Abrasion

Fatigue

Failure Mode (Safety)

Creep

Thermal

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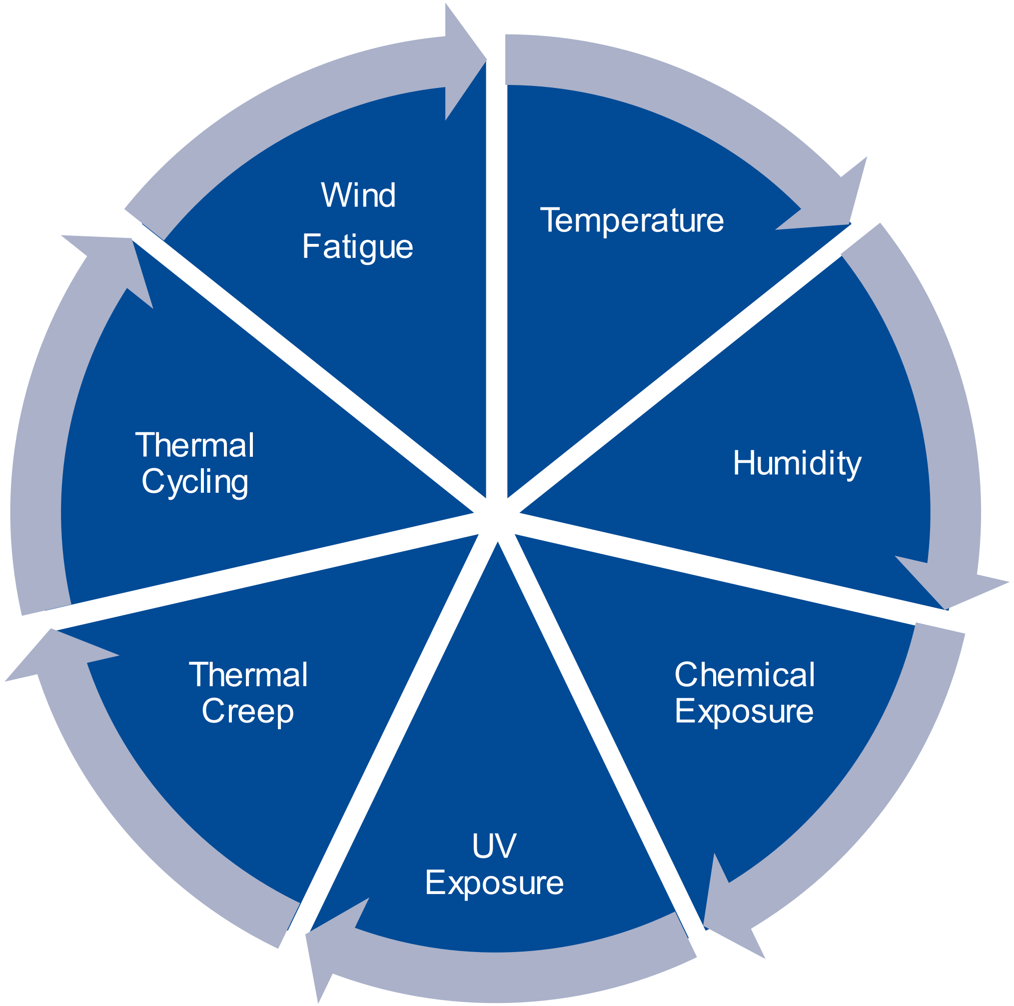
Environmental design considerations – Critical to material selection



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Material selection – Engineering plastics

Nylon (PA6, PA66, PPA)

- High strength
- Excellent toughness

Polyester PBT / PET

- Excellent dimensional stability
- Good electrical properties

Acetal POM

- Excellent sliding and friction properties
- Broad chemical resistance

Polysulfone PSU, PES, PPSU

- Very high heat resistance
- Excellent chemical resistance

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Covered in this section

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What is design?

- Definition:

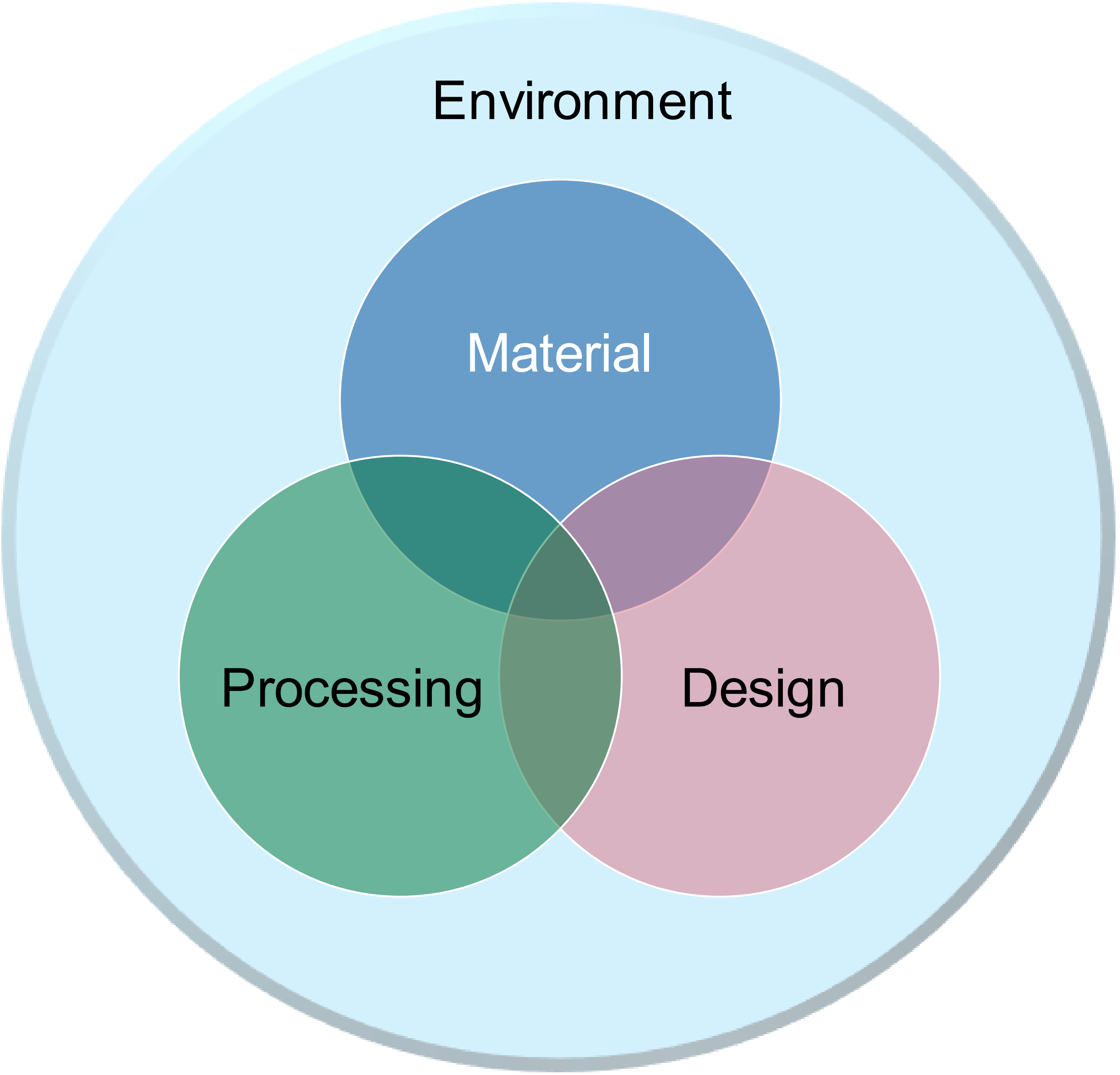
To create, execute or construct a plan that improves parts or details

i.e., “Make something better”

Basic steps in plastic design

1. Define part ***FUNCTIONS***
2. ***SKETCH*** part shape along with critical sections
3. Define applied ***LOADS*** (static, fatigue, impact, abrasion)
4. Estimate value of **STRESSES** by hand calculations
5. Investigate potential **MATERIAL** options
6. Determine **WALL THICKNESS** starting point
7. Conduct initial **STRESS ANALYSIS** by CAE
8. Conduct **MOLD FLOW** by CAE
9. ***OPTIMIZE*** the design based on CAE results
10. Make and test **PROTOTYPE** parts
11. ***REVISE*** design based on test results

For a successful engineered application in thermoplastics



Example of designing for extreme environmental situation

Datasheet Properties:

Mechanical properties		dry / cond.
Tensile modulus	MPa	10000 / 6170
Stress at break	MPa	170 / 112
Strain at break	%	3.5 / 11
Flexural modulus	MPa	8920 / 5650
Charpy unnotched impact strength (23°C)	kJ/m²	102 / 106
Charpy unnotched impact strength (-30°C)	kJ/m²	113 / -
Charpy notched impact strength (23°C)	kJ/m²	26 / 34
Charpy notched impact strength (-30°C)	kJ/m²	18 / -

-30% Humidity at 23C

-25% High Temp 80C

-10% UV Exposure 3-30 years

-10% Aging 15-30 years

= 2500 MPa
42.5 MPa

Conclusion: Fully understand the application's environment before selecting a material

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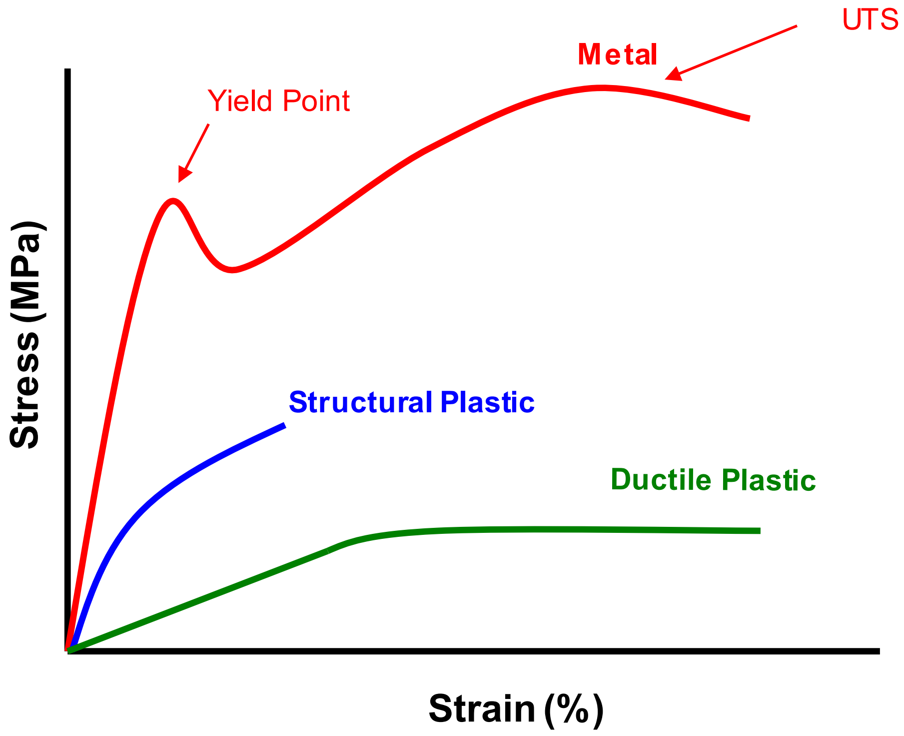
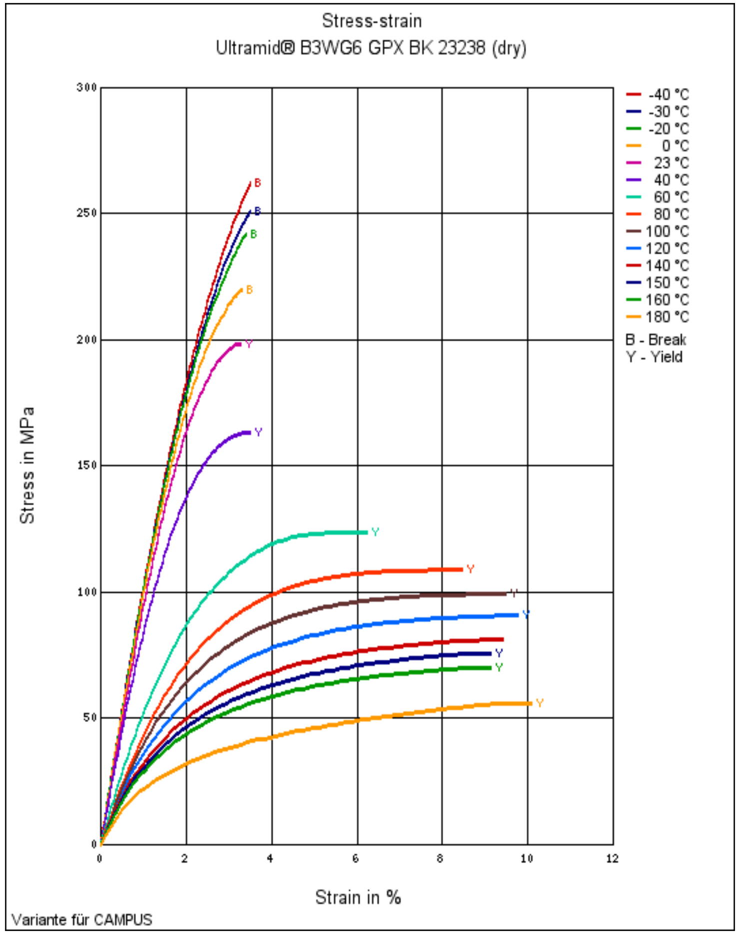
Stress strain curve overlay

Metals Exhibit
- Higher Strength & Stiffness



CAMPUS* Database



*CAMPUS (Computer Aided Material Preselection by Uniform Standards)

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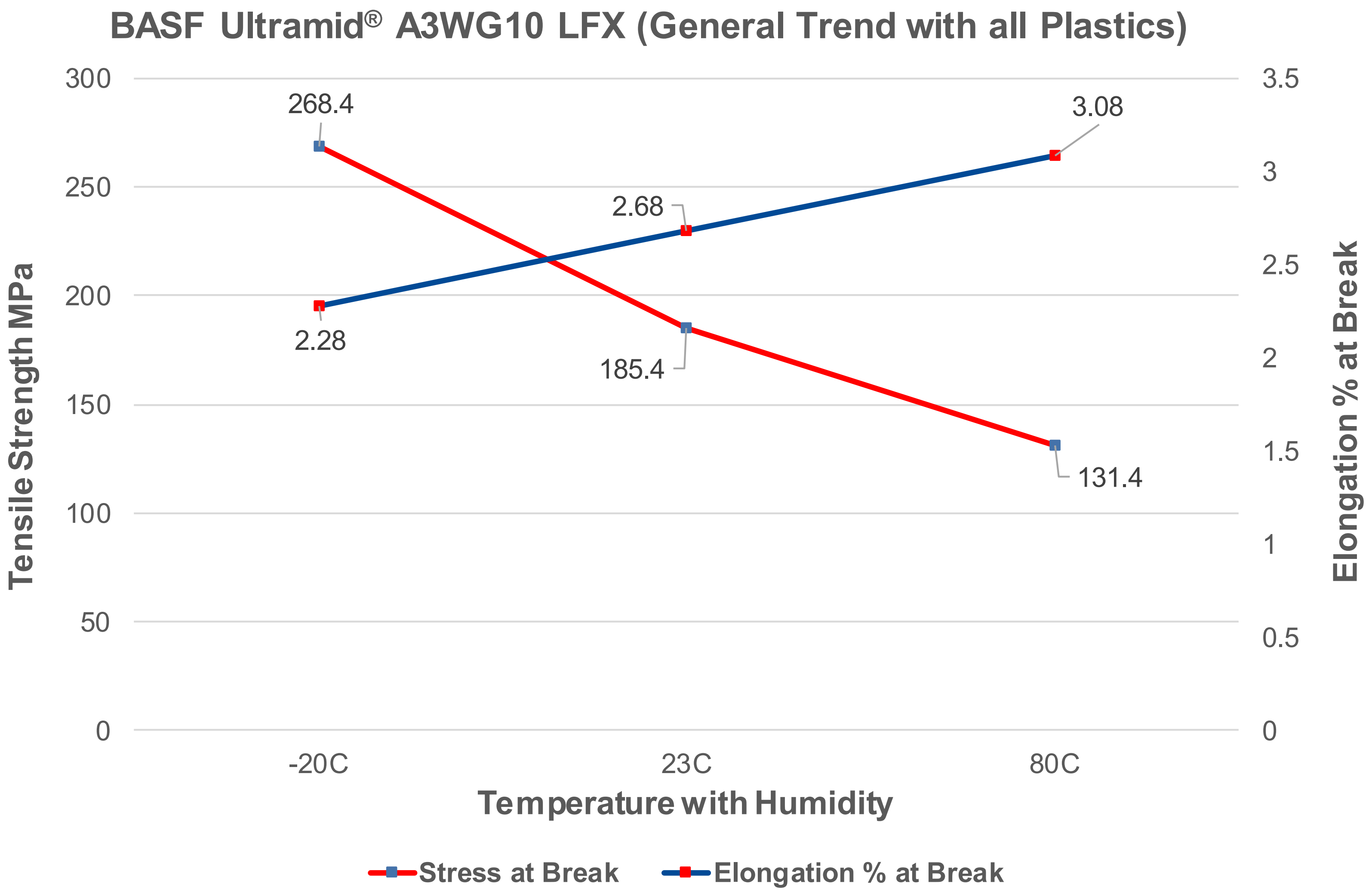
Balancing strength and elongation with temperature extremes



-20°C
- Increased strength
- Decreased elongation

80°C
- Decrease strength
- Increased elongation

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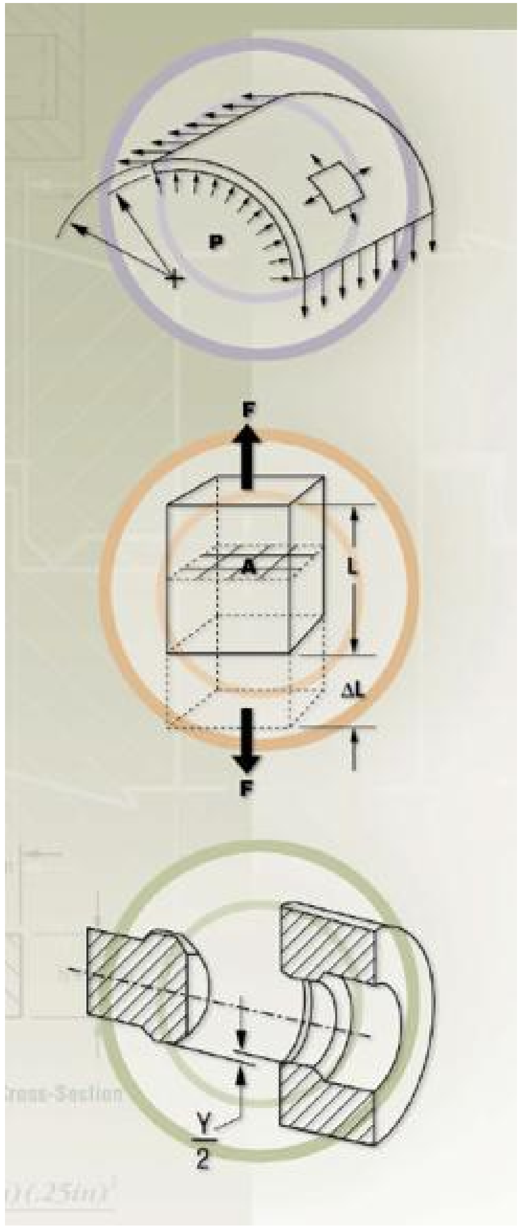
Plastic 101 design tips

- Things to remember about plastics
- Basic 'Rules of Thumb'



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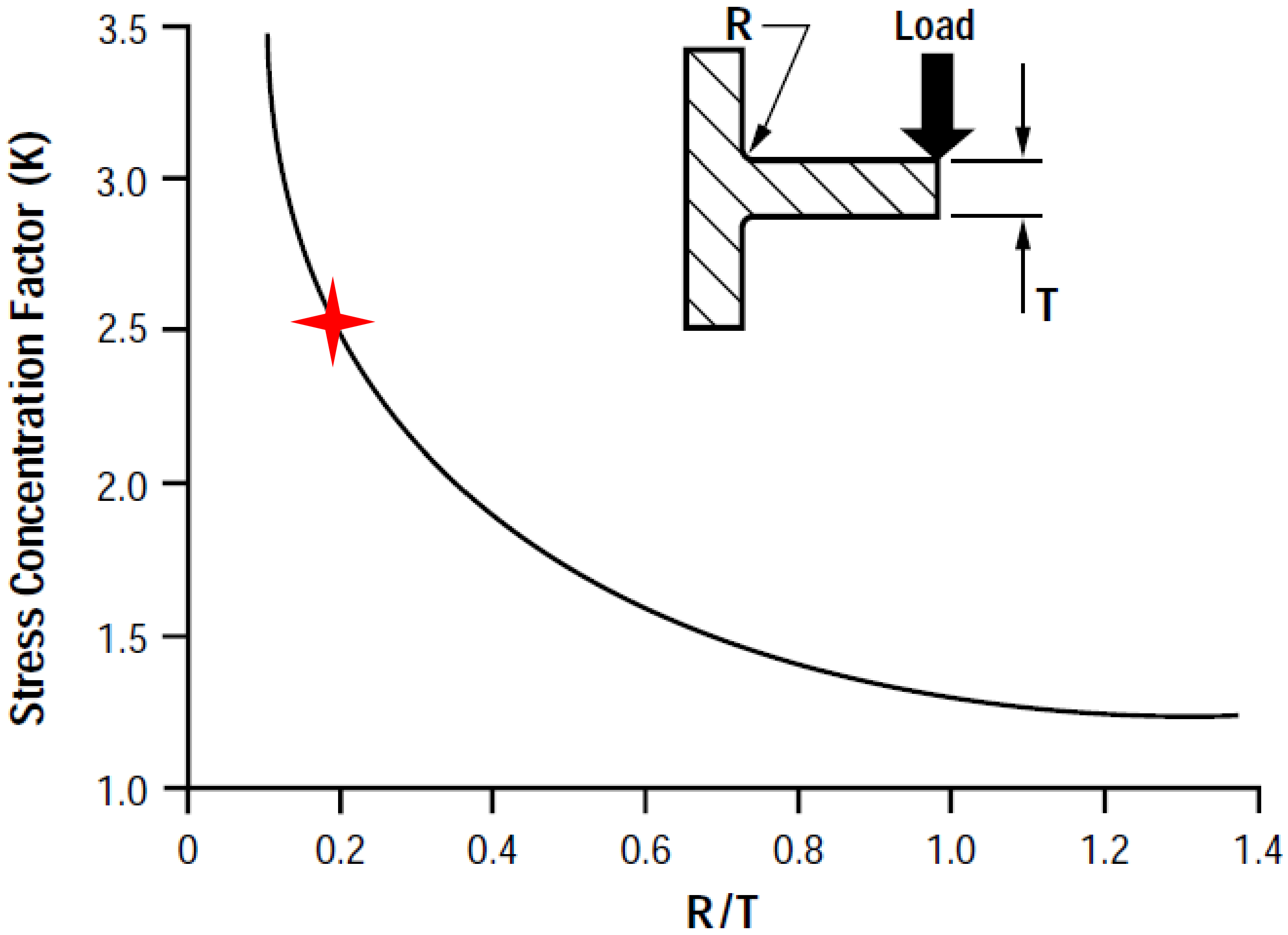
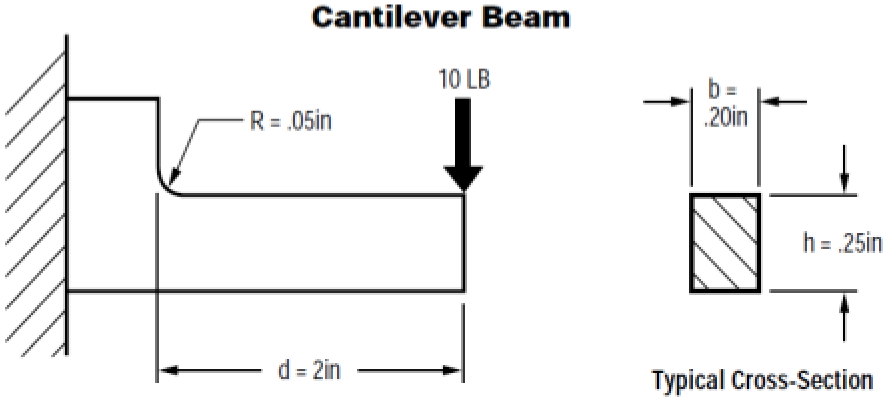
Uniform wall thickness

Corner stress concentration – Cantilever Beam example





$M = Fd$
$= (10lb)(2in)$
$= 20in\text{–}lb$

$C = \frac{h}{2}$
$= 0.125in$

$I = \frac{bh^3}{12} = \frac{(.20in)(.25in)^3}{12}$
$= 2.6 \times 10^{-4} in^4$

Wrong Way

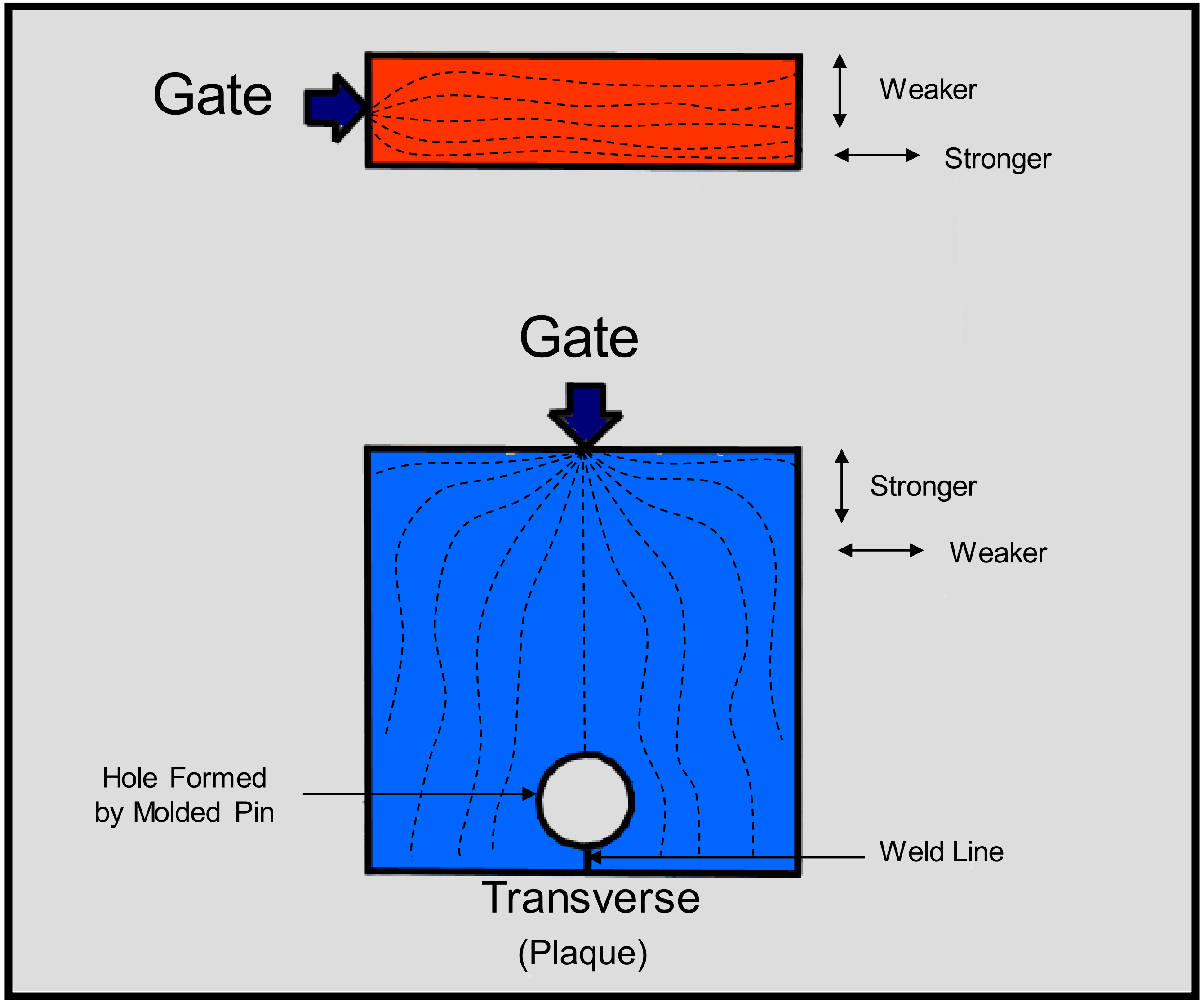
$\sigma = \frac{Mc}{I}$
$= \frac{(20in\text{–}lb)(.125in)}{2.6 \times 10^{-4} in^4}$
σ = 9600 psi

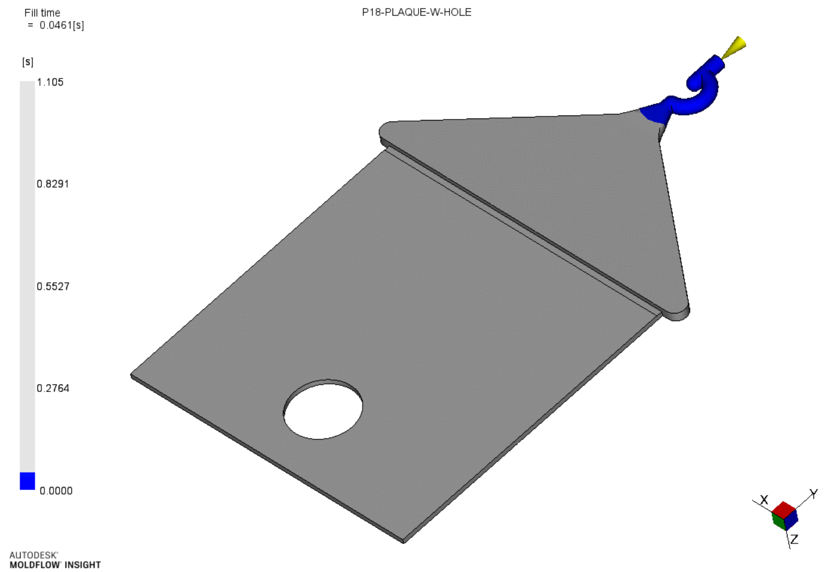
Right Way

$\sigma = K\frac{Mc}{I}$
$\frac{R}{t} = \frac{.05in}{.25in} = .2$
$K = 2.5$
$\sigma = 2.5(9600\ psi)$
σ = 24000 psi

Conclusion: Largest Radius the Design will Allow

Glass filled polymers – Fiber orientation





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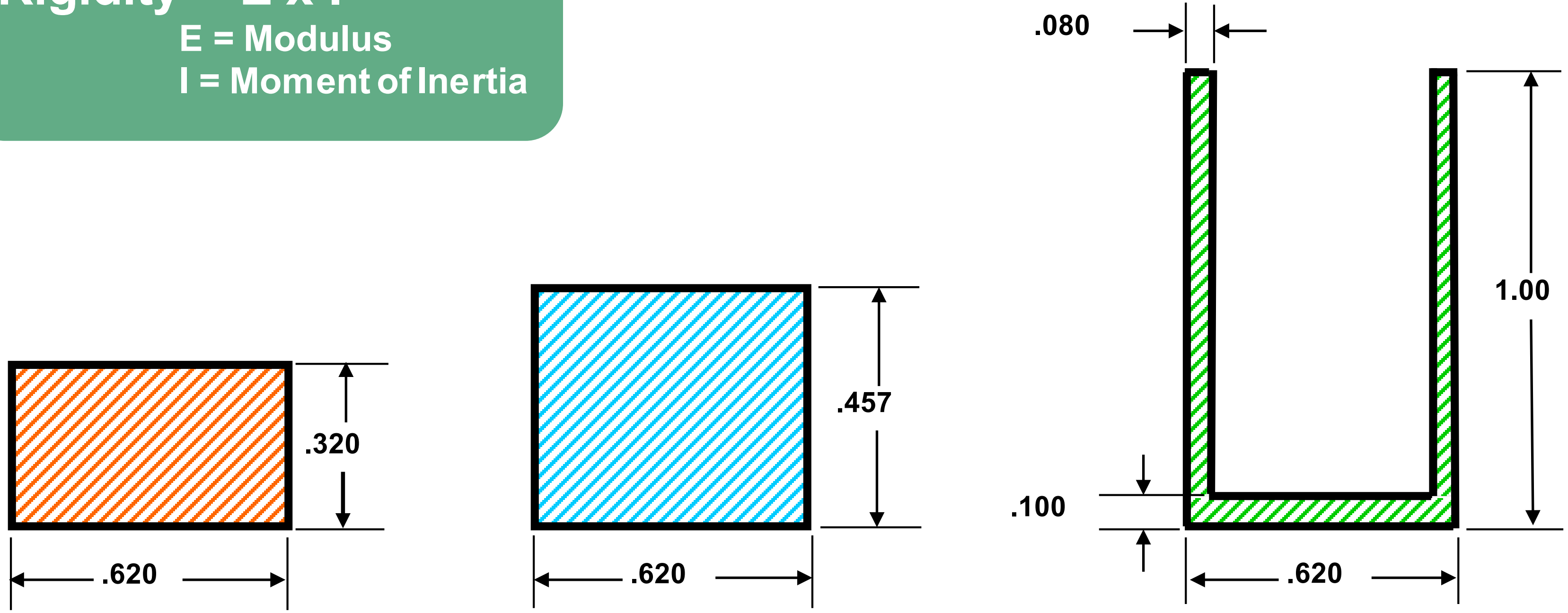
Equivalent stiffness example

Rigidity = E x I
E = Modulus
I = Moment of Inertia

Equivalent Stiffness
$I_{Plastic}$ >>> I_{METALS}

$$I = \frac{BH^3}{12}$$



Steel
E = 30 x 10^6
I = 0.0017
E x I = 5.08 x 10^4
A = 0.198

Aluminum
E = 10.3 x 10^6
I = 0.0049
E x I = 5.08 x 10^4
A = 0.283

Polyamide (33% GR)
E = 1.2 x 10^6
I = 0.0424
E x I = 5.08 x 10^4
A = 0.17

Covered in this section

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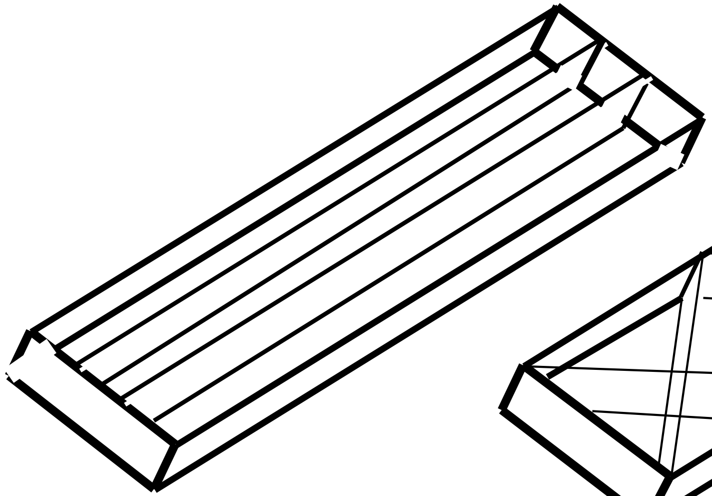
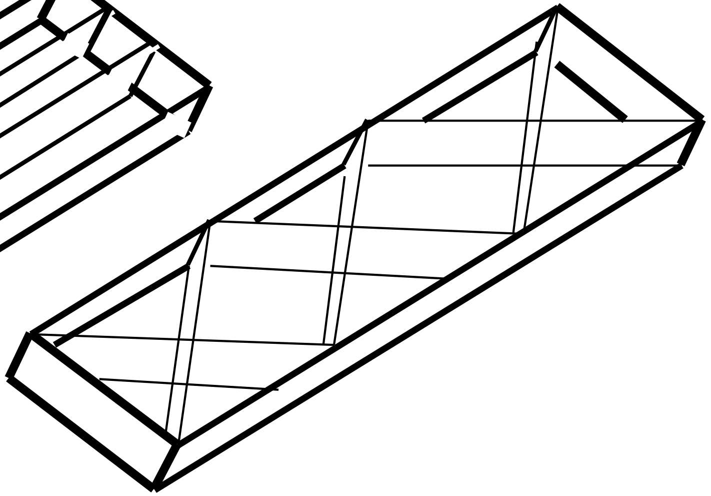
Add ribs to increase structure

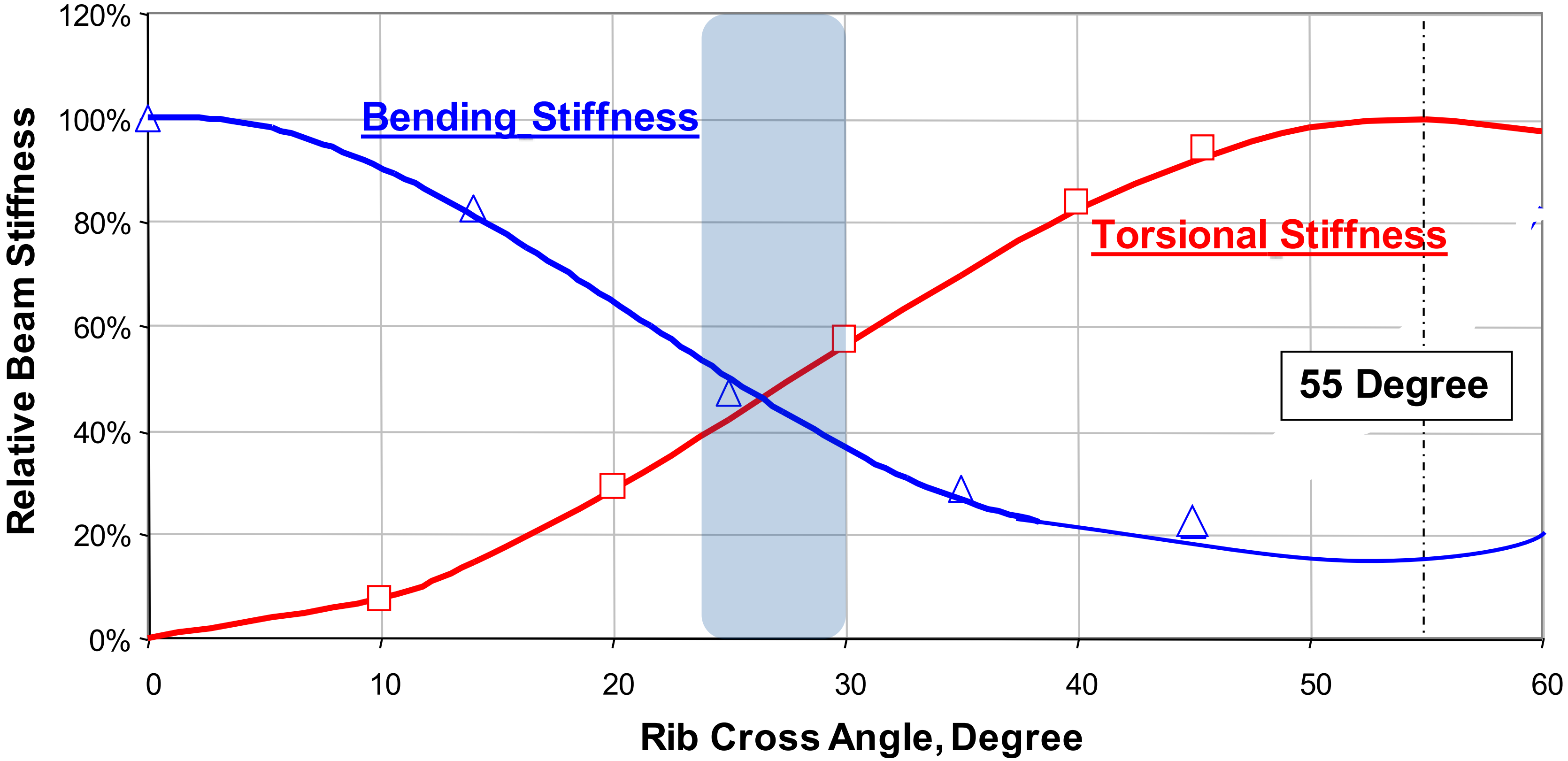


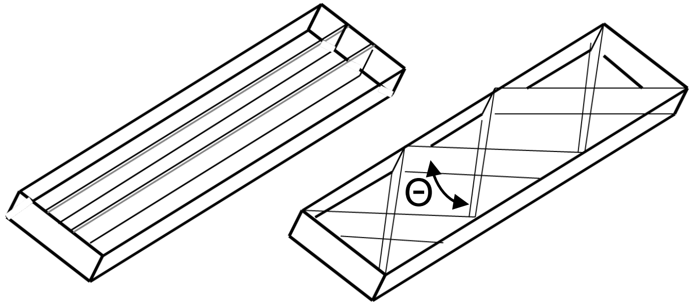
Straight Rib



Cross Rib

Design guidelines – Influence of rib angle on beam stiffness





Cross Ribs

Optimal Rib Angle: 25 – 30 Degrees
for ***BOTH*** Bending & Torsional Stiffness

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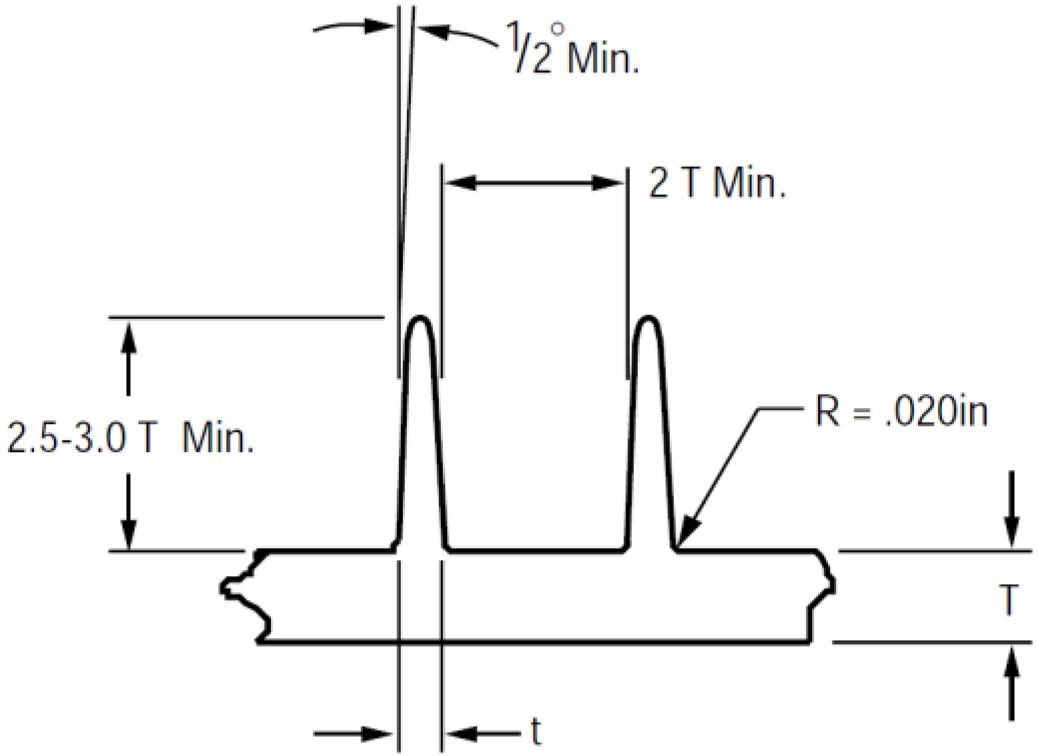
Increasing plastic performance with structural ribs



- In **structural parts** where sink marks are of no concern, rib base thickness (t) can be **75–85%** of the adjoining wall thickness (T).
- In **appearance parts,** (t) should be **<50%** of the adjoining wall thickness (T) if the outside surface is textured and **<30% if not textured.**
- Rib height should be at least 2.5–3.0 times the wall thickness (T) for effective strength.
- Draft should be 1/2° per side nominal.
- Multiple ribs should be spaced at least 2T apart to reduce molded in stress and problems in cooling of the mold.

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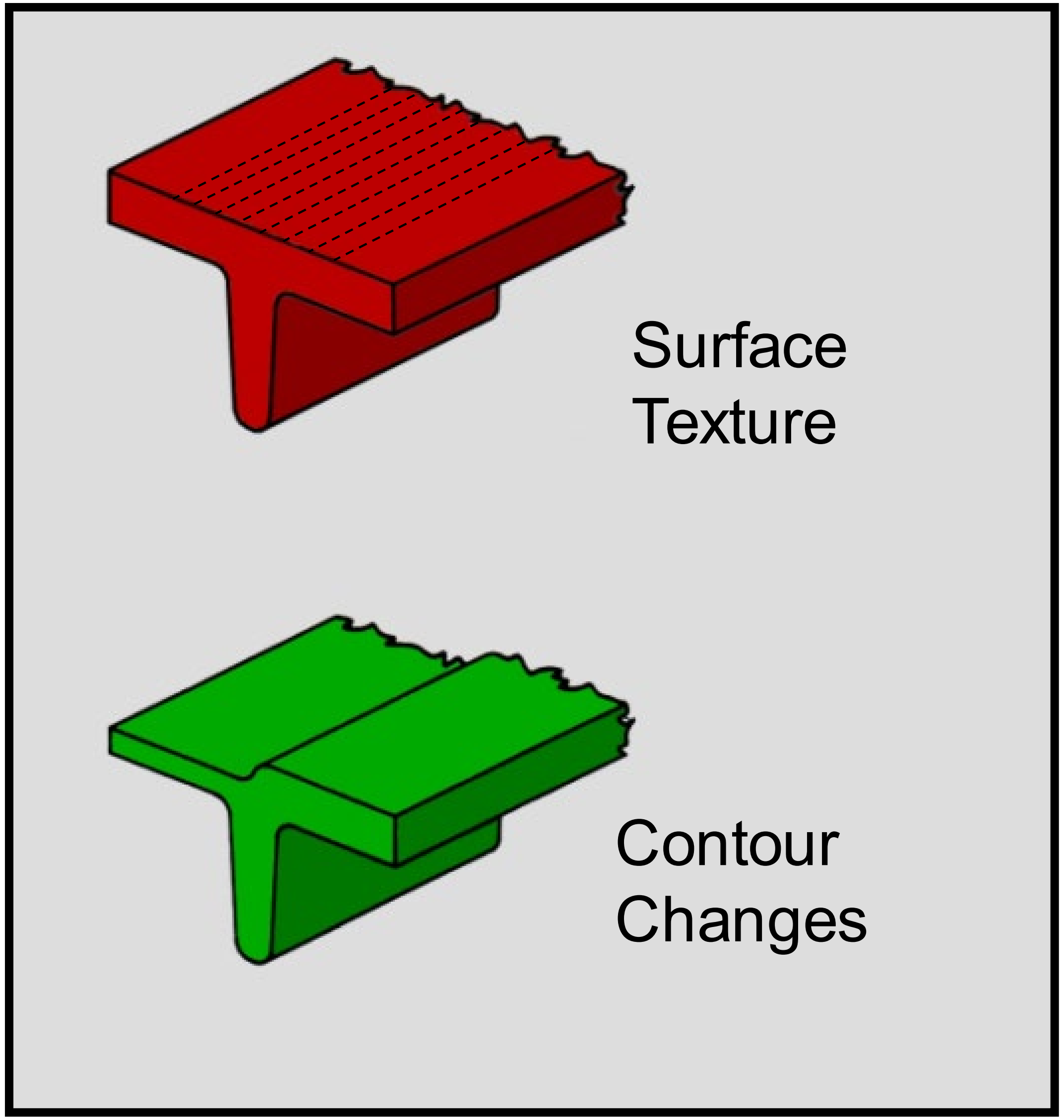
Structural ribs – Hiding sink marks



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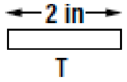
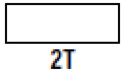
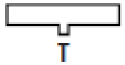
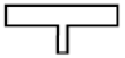
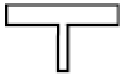
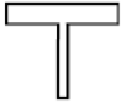
Increasing plastic performance with structural ribs – Competing with metals in deflection and stress

Effect of 1/8in Thick Rib of Various Heights on the Strength of a 2in x 1/4in Beam					
Case Number	Shape	Rib Size	Rib Height/ Wall Thickness	% Increase in Weight	% Increase in Stiffness
0		N/A	N/A	N/A	N/A
1		N/A	N/A	100	700
2		1/8in W x 1/8in H	1:2	3.12	23
3		1/8in W x 1/4in H	1:1	6.25	77
4		1/8in W x 1/2in H	2:1	12.5	349
5		1/8in W x 3/4in H	3:1	19.0	925

Increasing Stiffness to Weight Ratio

Conclusion: Use plastic's advantage of ribs and maximize height

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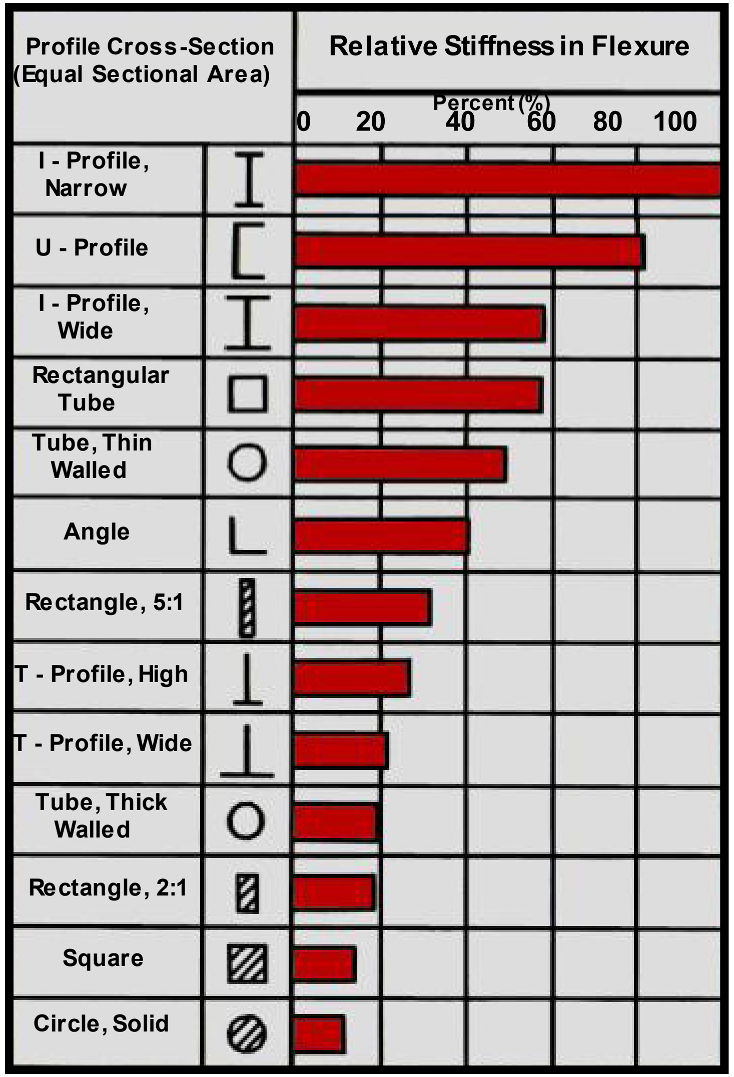
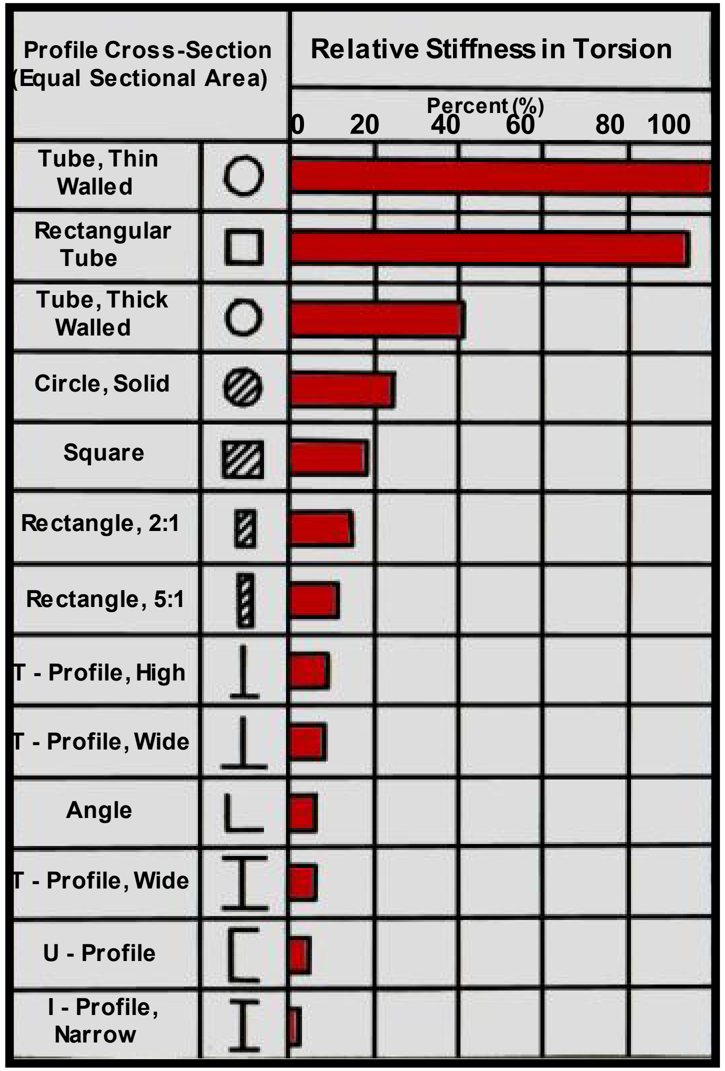
Beam stiffness chart – Flexural and torsion

Beam Stiffness in Flexural Comparison



Beam Stiffness in Torsion Comparison



Various profiles with equal cross-section areas

Actual part design history – Cruise control bracket

Problem: Bracket Bending Under Load

Reason for part failure

Material?

Processing?

Design?

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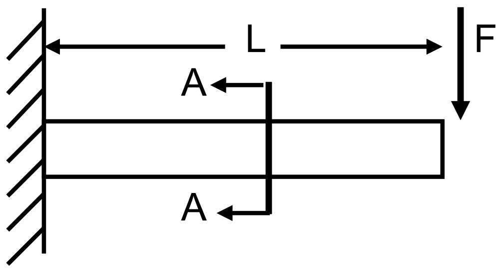
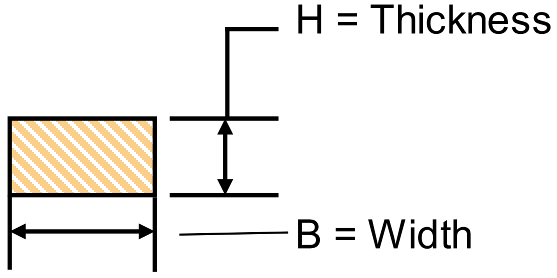
Rigidity equation

$$R = EI$$

Simple Cantilever Beam





Modulus of Elasticity, E

R can be increased by increasing E

Moment of Inertia, I

$$I = \frac{BH^3}{12}$$

A small increase in H translates into a large increase in I, which in turn will increase R.

Example: If H is doubled, I will be increased by a factor of 8!

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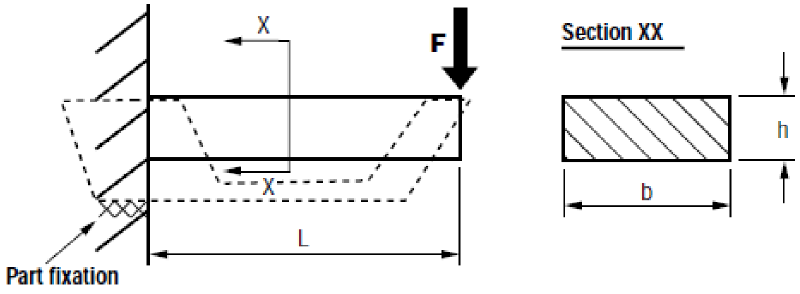
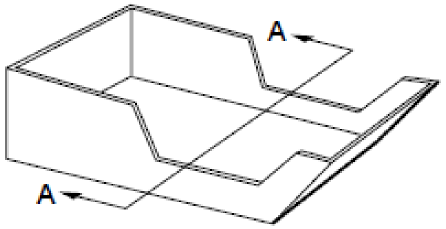
Increasing plastic performance with structural ribs – Competing with metals in deflection and stress

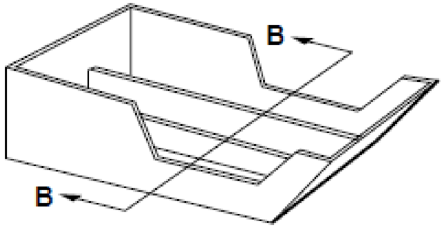


Rigidity Modulus, R = EI

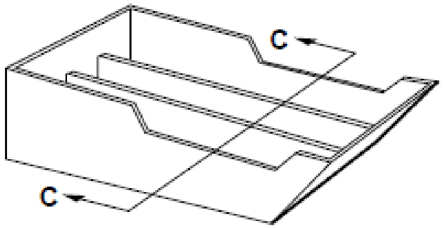
E = Modulus of Elasticity
I = Moment of Inertia
R can be increased by increasing E or I



Steel Part

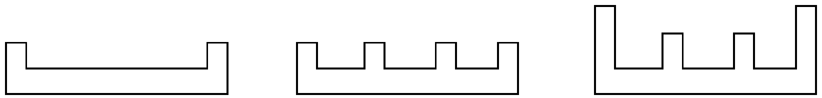


Present Plastic Part



Redesign

Section AA	Section BB	Section CC
	Plastic	
Original Steel Part	Present Part	Redesign



I = .0002 EI = 6,000	I = .0008 EI = 592	I = .041 EI = 30,340

E for plastic = 740,000 psi (PA6 +33%SGF) at 50% RH
E for steel 30,000,000 psi **(40.5X plastic)**

Since $I = bh^3/12$, a small change in h will result in a cubed effect or a large increase in R, a very effective change.

Conclusion: Gain Performance through Section’s Moment of Inertia

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Covered in this section

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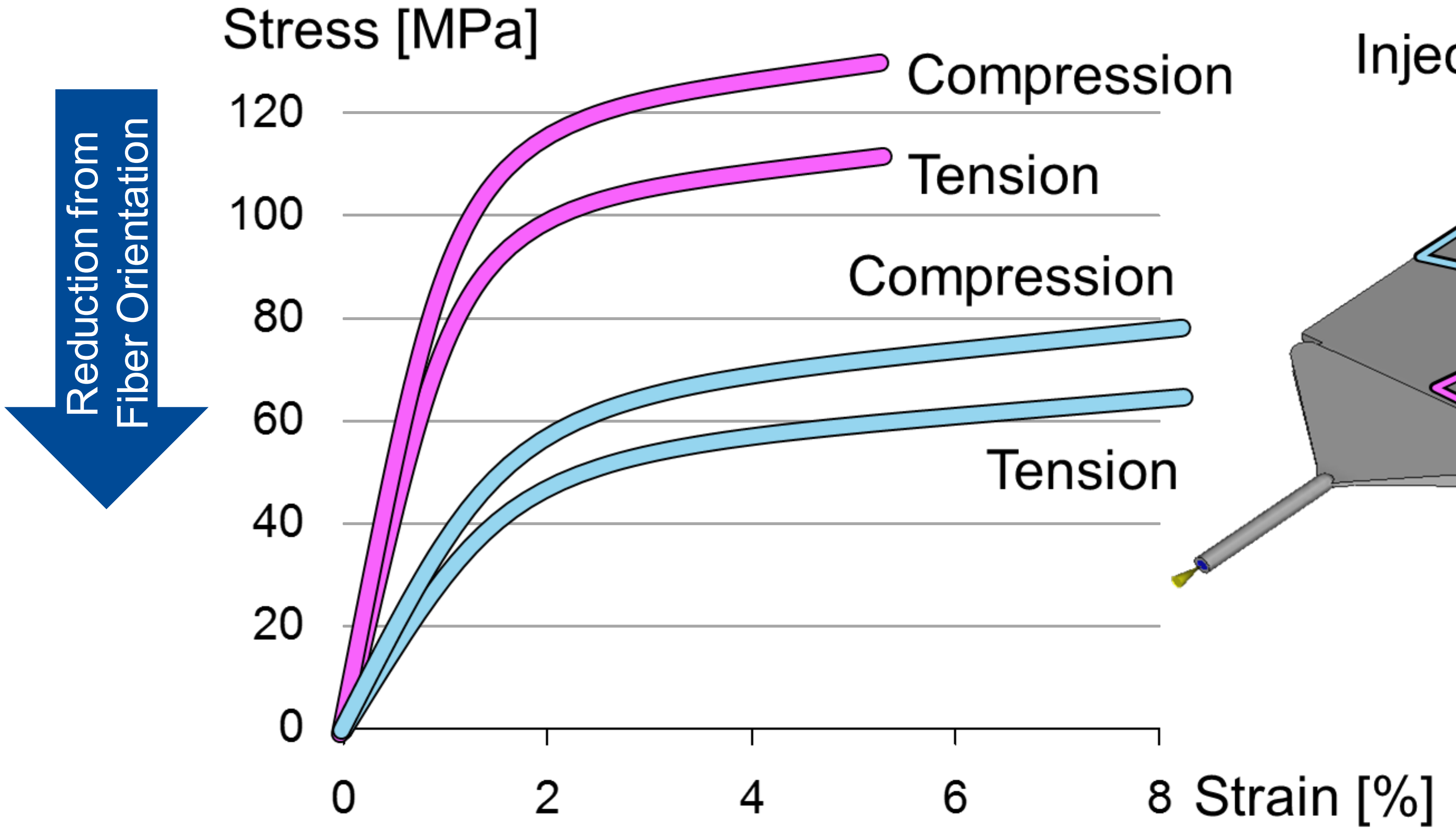
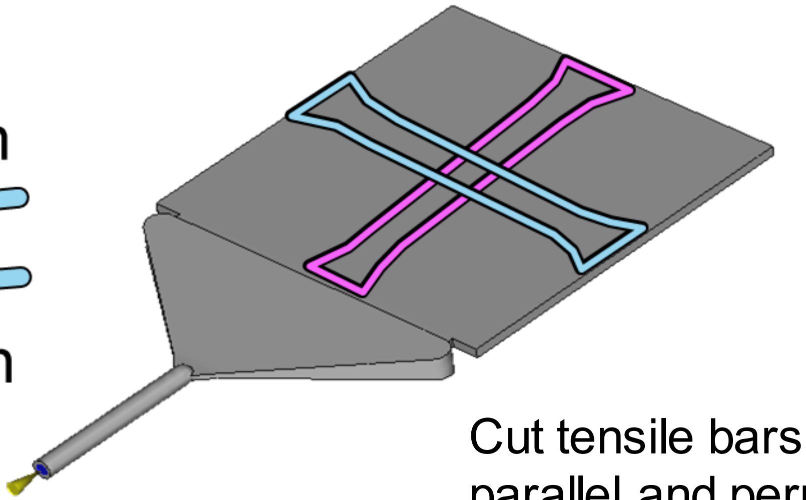
Fiber orientation material characterization – GF Nylon



Injection molded plate



Cut tensile bars parallel and perpendicular to melt flow direction

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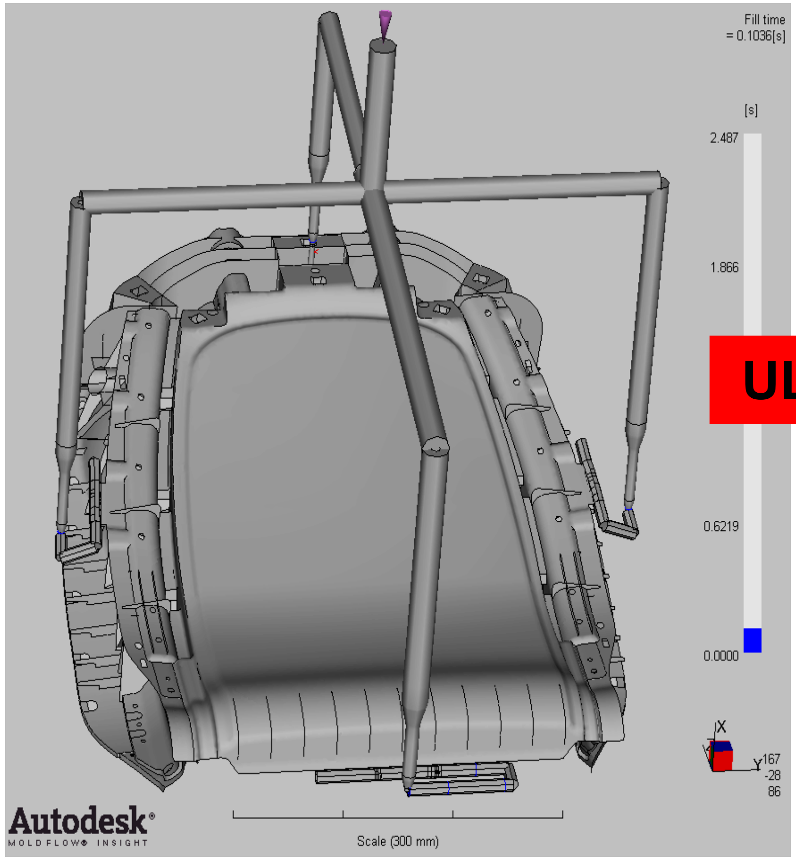
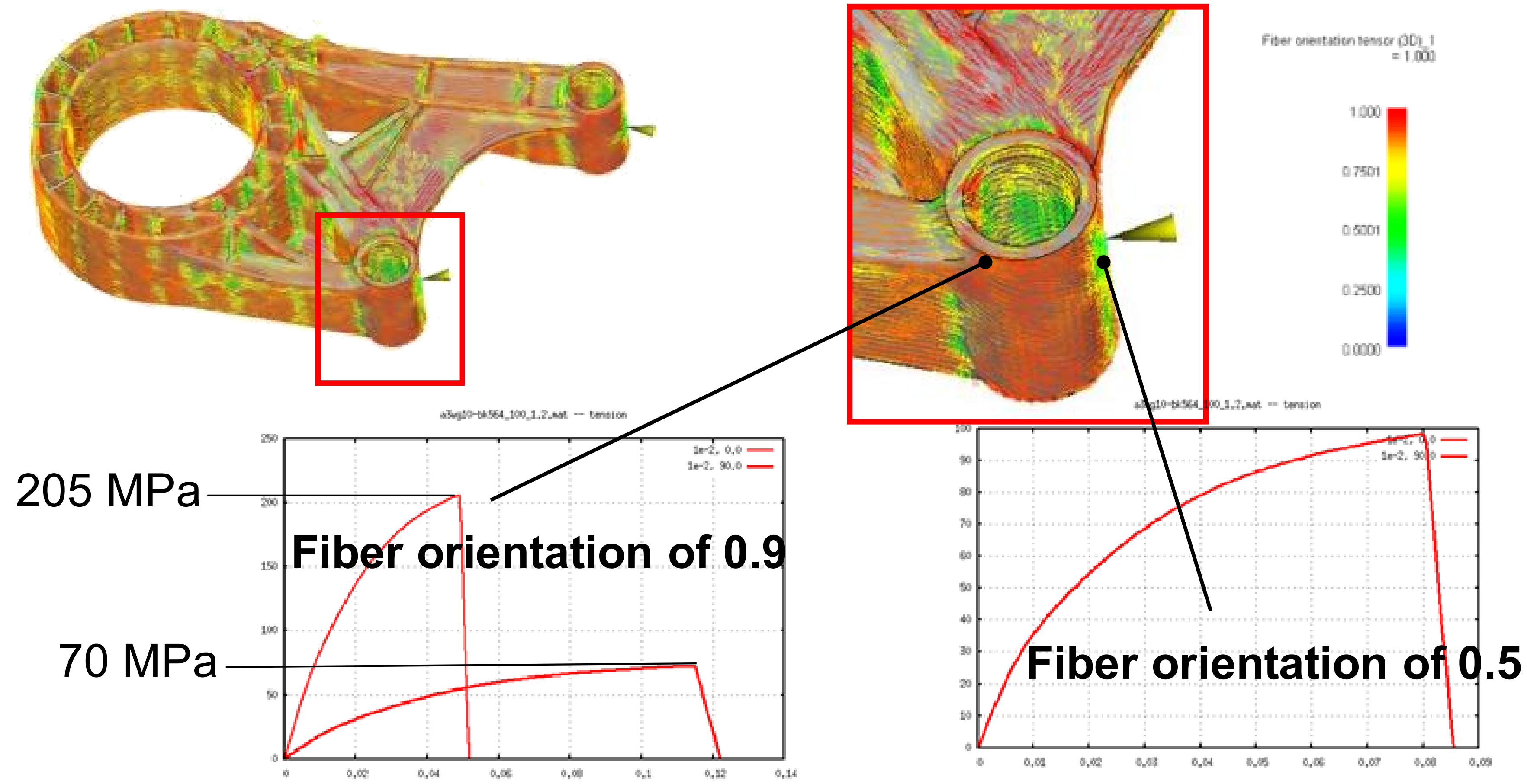
Fiber orientation material characterization – GF Nylon

Every finite element is assigned a unique mechanical property



ULTRASIM®

Mold filling CAE for fiber orientation and material behavior



Conclusion: Higher strength in critical location with optimized gating

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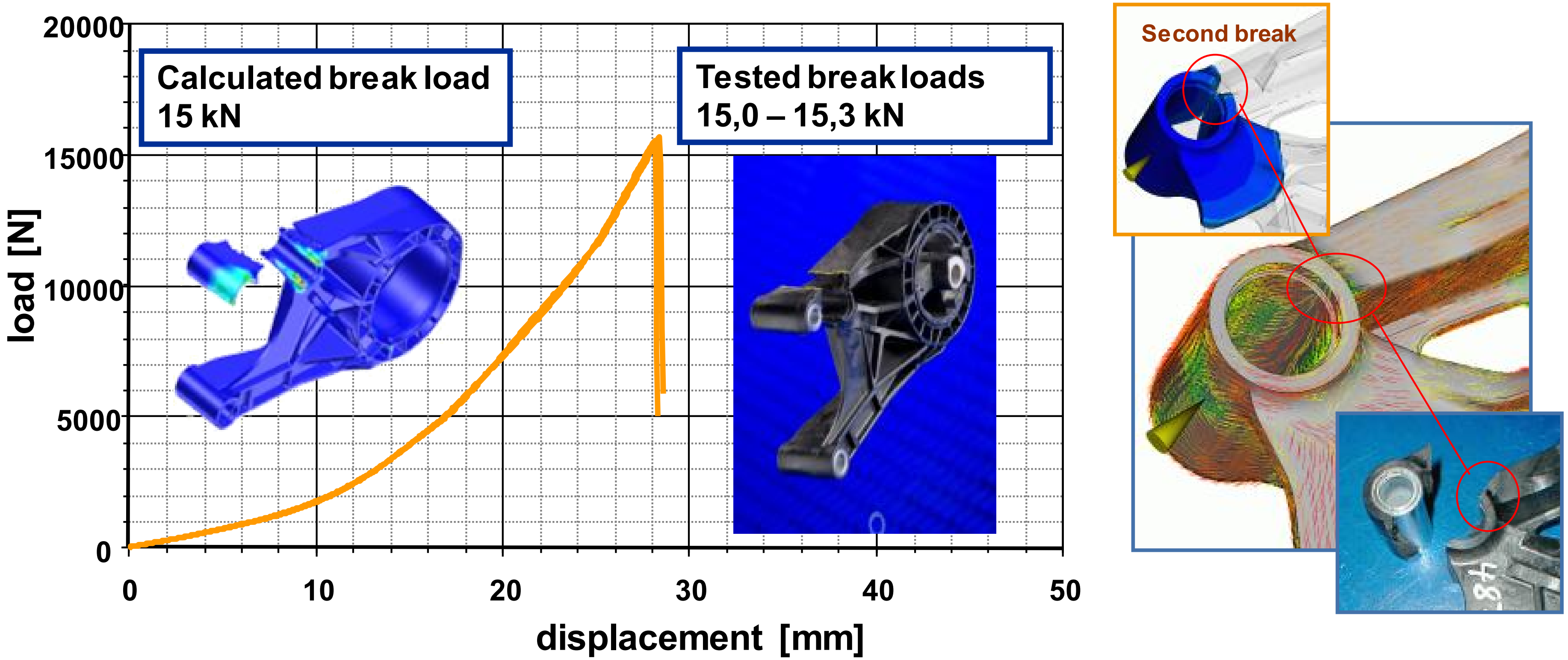
Highly precise CAE for physical testing correlation



Covered in this section

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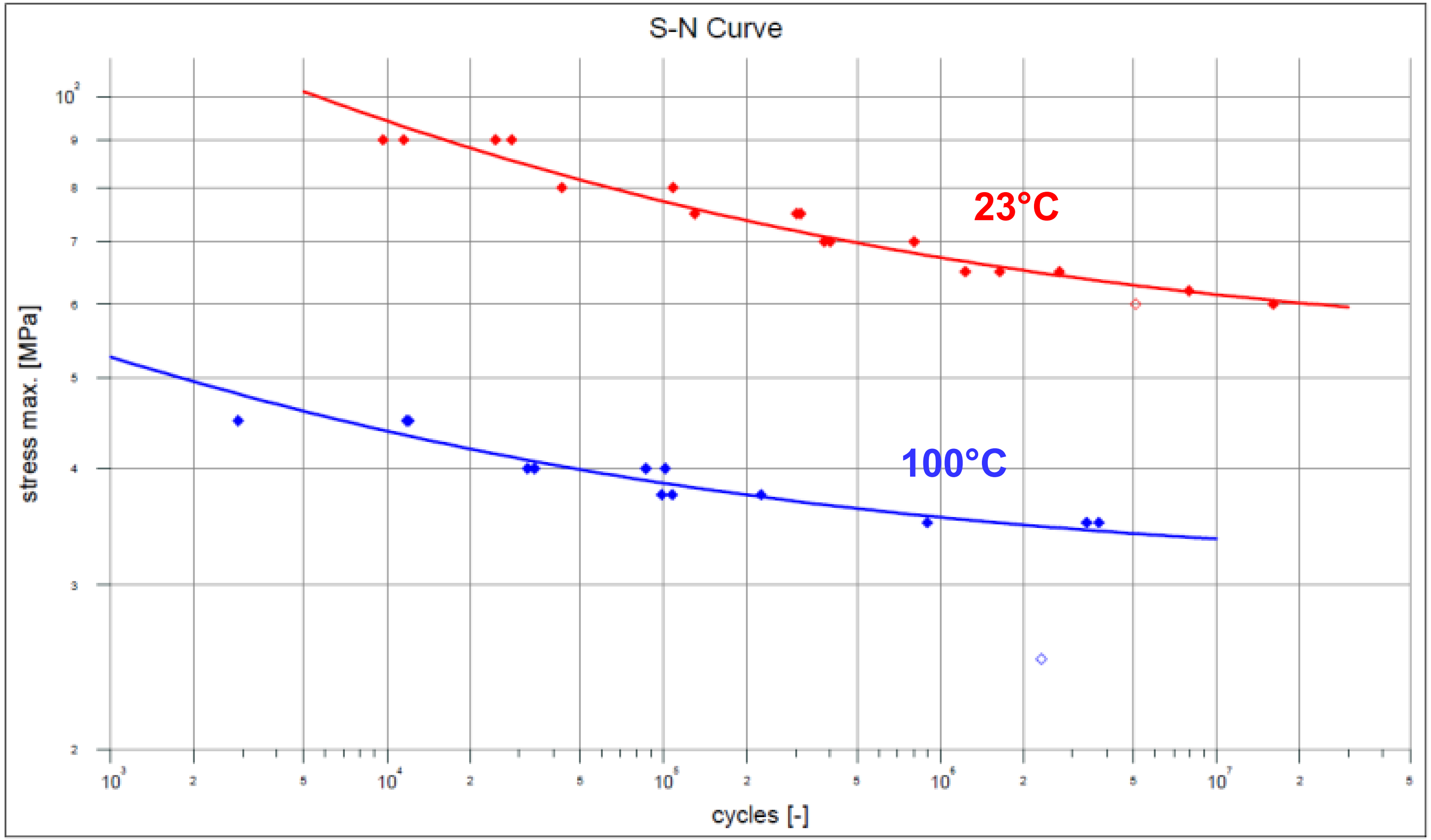
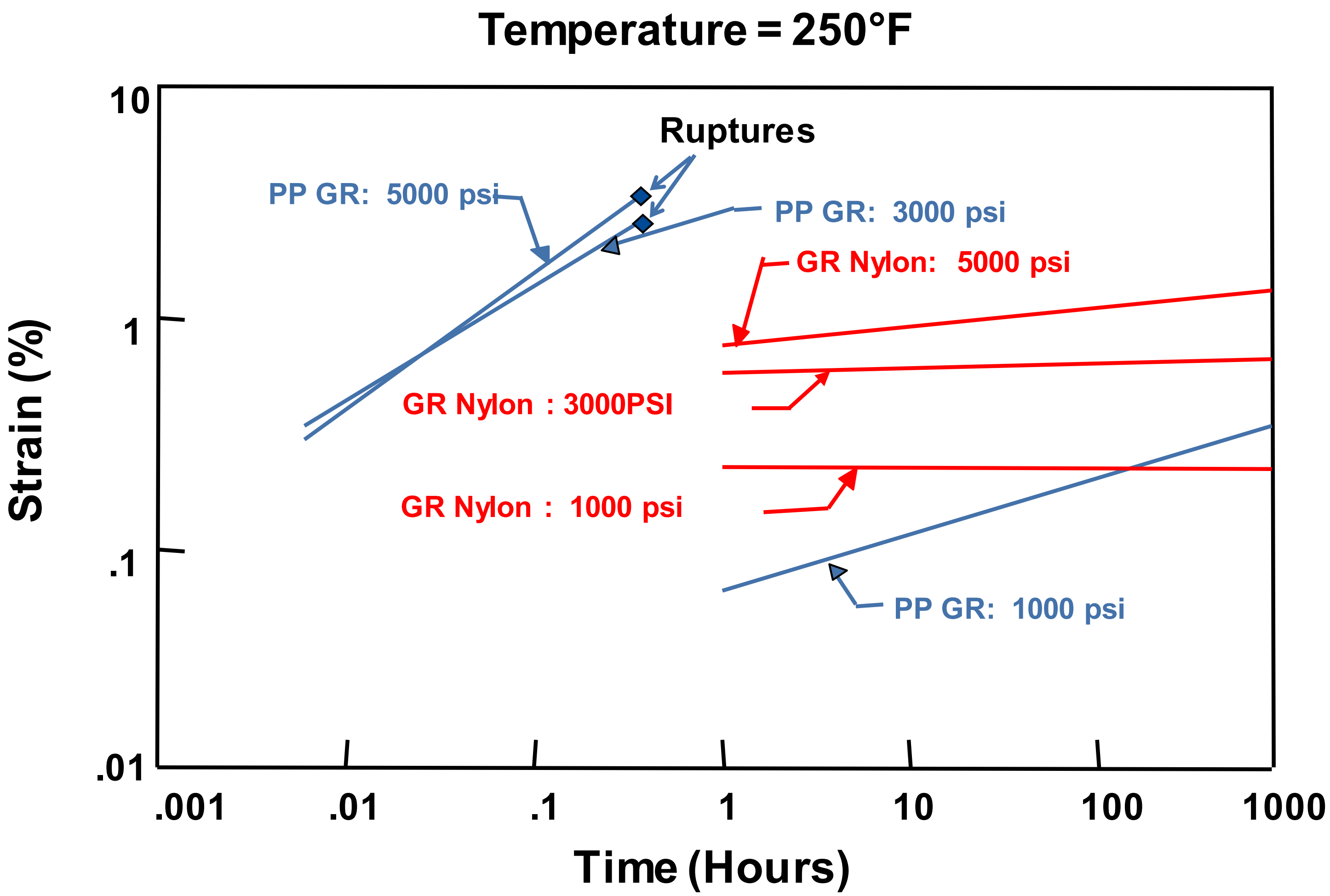
Long-term properties – Fatigue



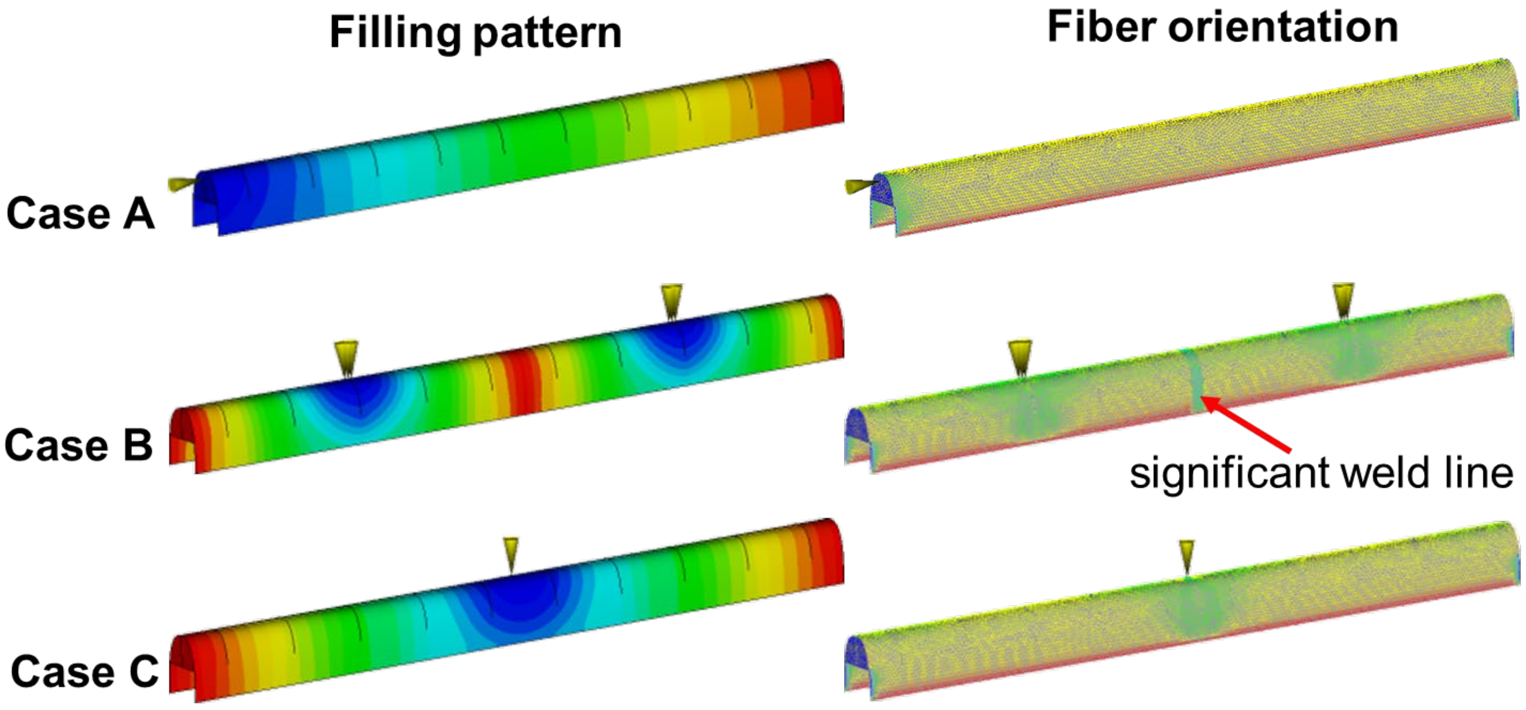
Designing based on S-N curves prevent fatigue failures

Creep curves – GF nylon versus GF polypropylene



GR = Glass reinforced

Gating considerations



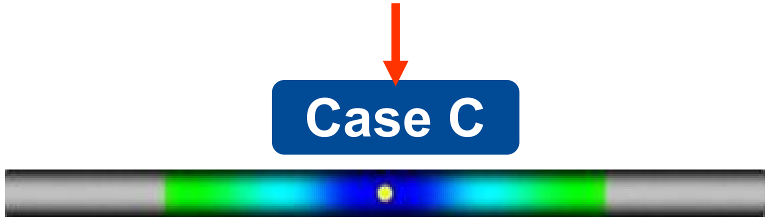
- Gates should be located away from high stress or impact areas.
- Gate configuration and location should minimally affect part appearance.
- Gates should be located to best fill the part for optimal fiber orientation and locate knit lines in low-stress areas

BASF
We create chemistry

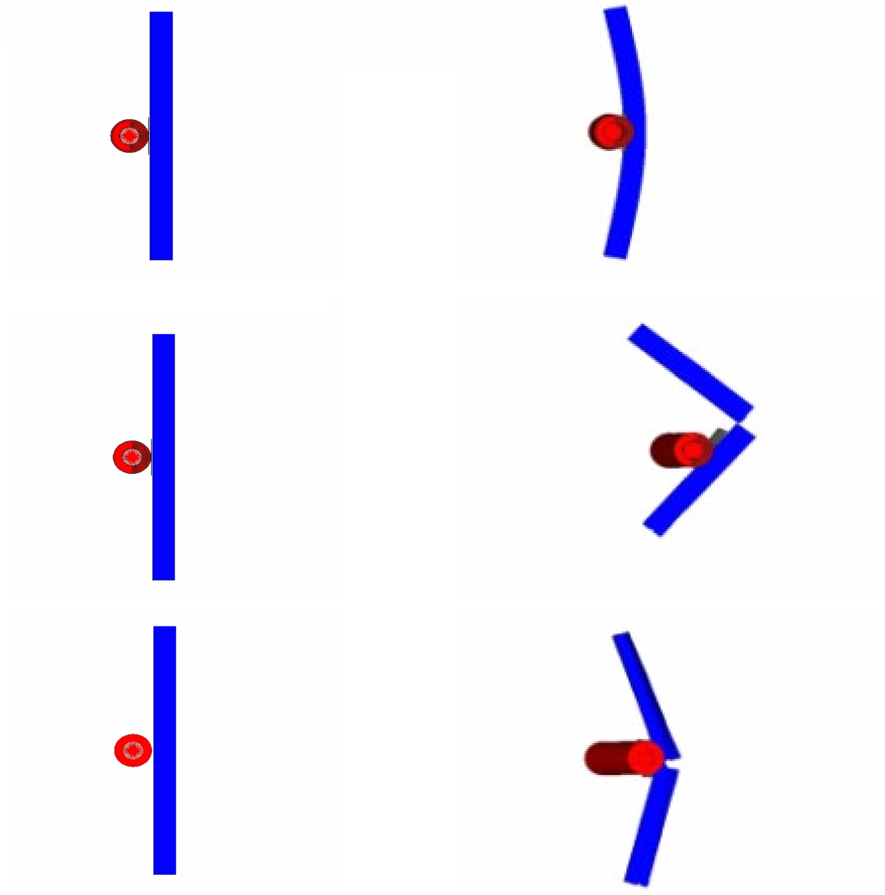
Example: Ultrasim® for simple beam – Accurate prediction of failures

Case A: Part *without* failure!

Case B: Failure!



Case C: Failure!



Conclusion

Why convert to Plastics?

- Cost & Weight reduction
- Part consolidation for ease of assembly
- Improved aesthetics

How?

- Using good plastic design principles
- Identifying & designing for the worse case conditions/ properties
- Using CAE (complex parts) to confirm design before building tool

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