Filled Plastics Facts & Fallacies

Dr. Chris DeArmitt FRSC

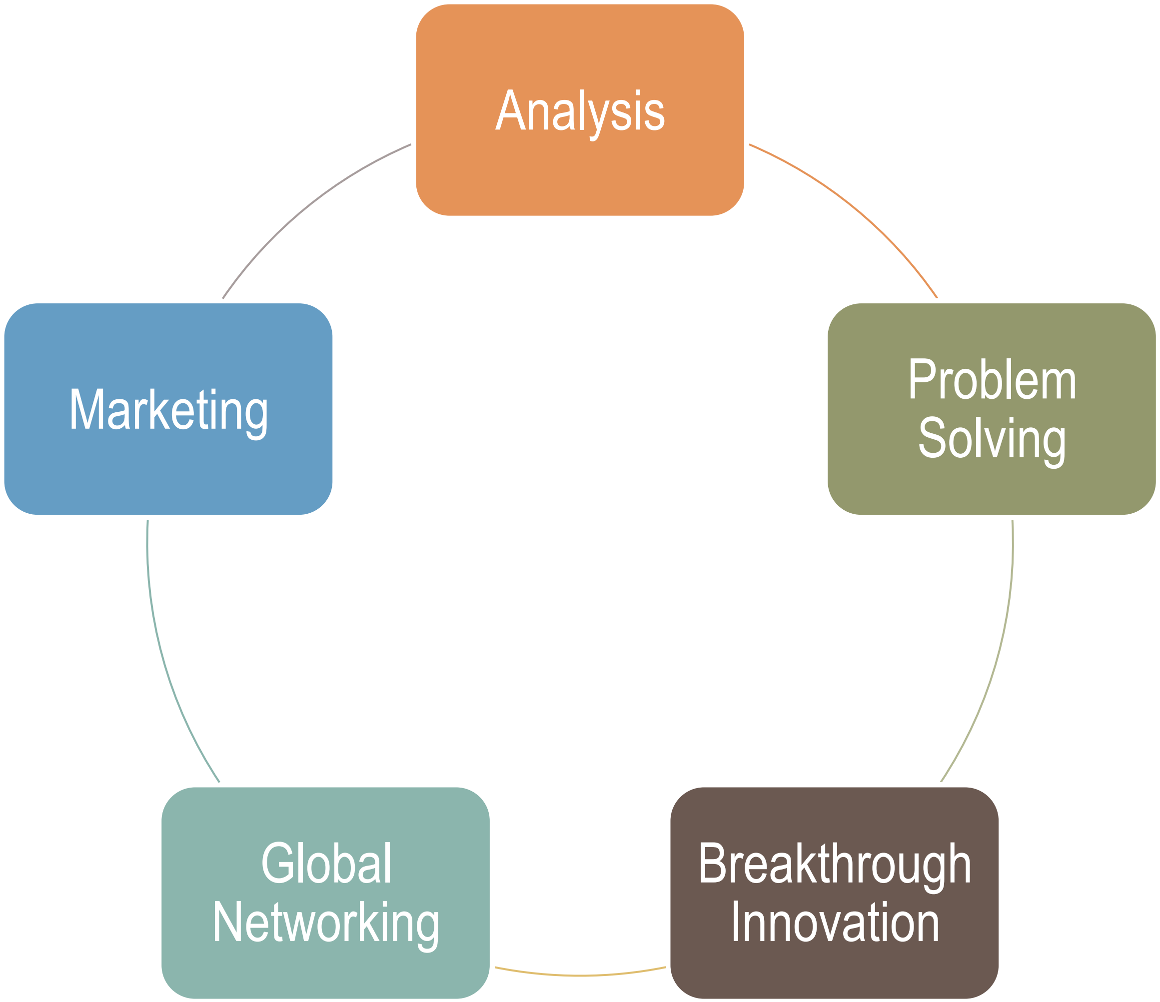
Your presenter

A combination of technical expertise and business savvy

- Over 15 years of experience in innovation and industry: Cookson, Institute for Surface Chemistry (YKI), Electrolux, BASF, Hybrid Plastics & Phantom Plastics
- Recognized expert in plastics, filled plastics, fillers, dispersants, coupling agents, formulation, stabilization and more
- Serial innovator: many inventions, 13 patents & 3 Innocentive cash awards
- Papers, articles, book chapters, presentations & workshops
- Fellow of the Royal Society of Chemistry & Chartered Chemist
- Winner of Frost & Sullivan award 2009 and R&D 100 Award 2009
- Voted top plastics expert world-wide out of over 10 000 peers
- President of Phantom Plastics providing consultancy and training services to the plastics industry

Phantom Plastics™ capabilities

Many faceted approach to deliver solutions



Outline

A foundation for working with polymers and composites

- Introduction to fillers and polymers
- Common fillers and their characteristic properties
- Common polymers and how structure affects their properties
- How fillers affect polymer processing and properties of polymers
- Cheat sheet summarizing how all these factors influence the properties of the composite
- Misconceptions about filled plastics
- Further reading, consultants, web resources

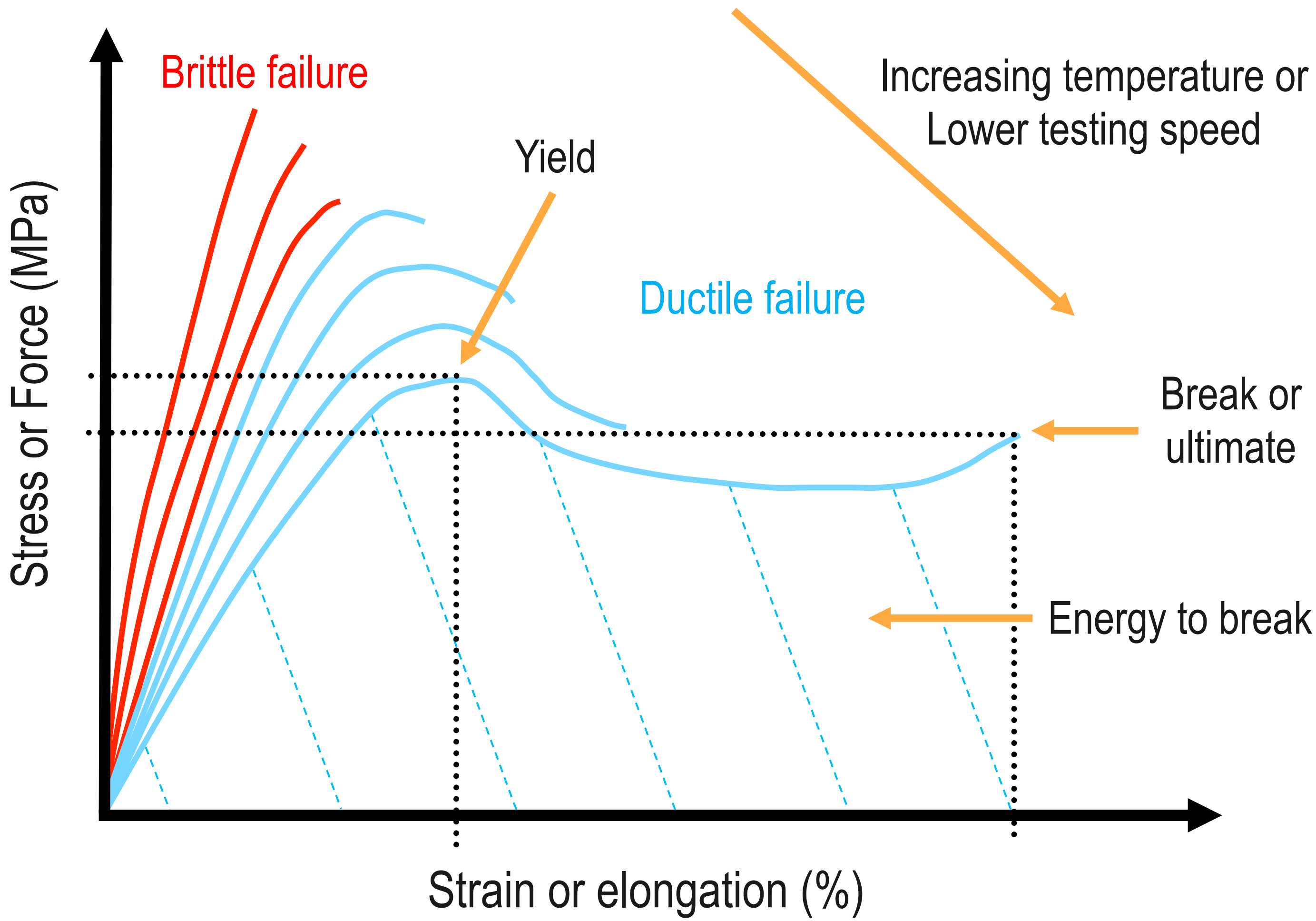
Reasons to use fillers

Innumerable different reasons to use fillers

- Raise heat resistance
- Increase stiffness
- Increase strength
- Reduce shrinkage
- Improve dimensional stability
- Reduce flammability
- Modify flow
- Increase lubricity
- Decrease permeability
- Increase degradability
- Improve processability
- Reduce creep
- Change electrical properties
- Modify specific gravity
- Improve abrasion resistance
- Improve impact strength
- Improve thermal conductivity
- Improve moisture resistance
- Increase adhesion
- Appearance, opacity, gloss

Basic polymer mechanical properties

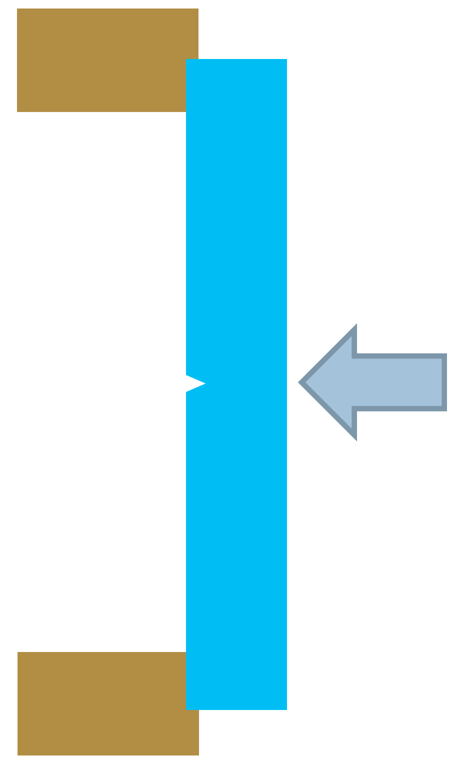
Polymer behavior depends on testing speed and temperature



Impact test methodology

The notch provides crack initiation and helps consistency

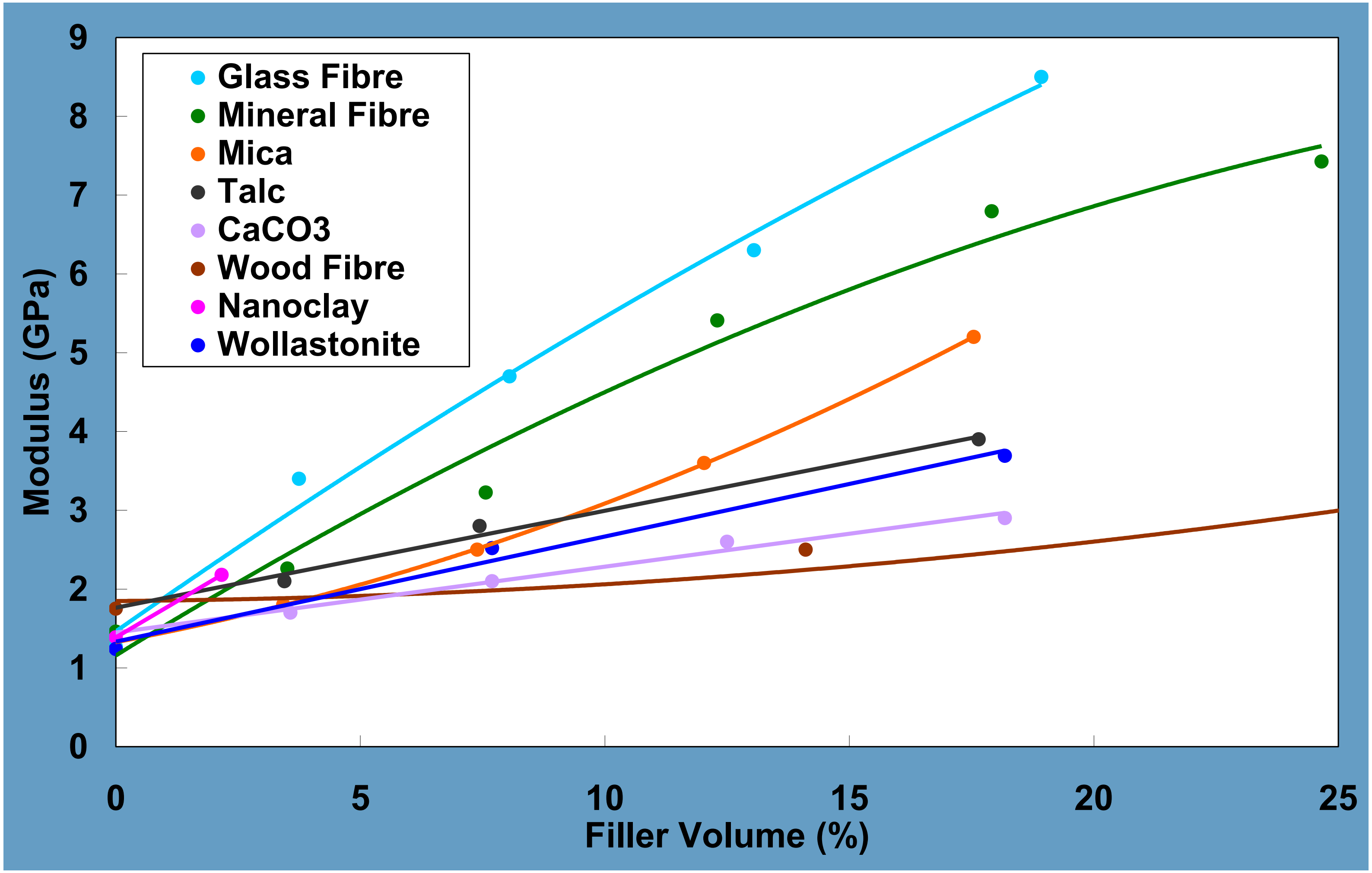
Notched Izod



Notched Charpy

Fillers improve modulus

High aspect ratio is best



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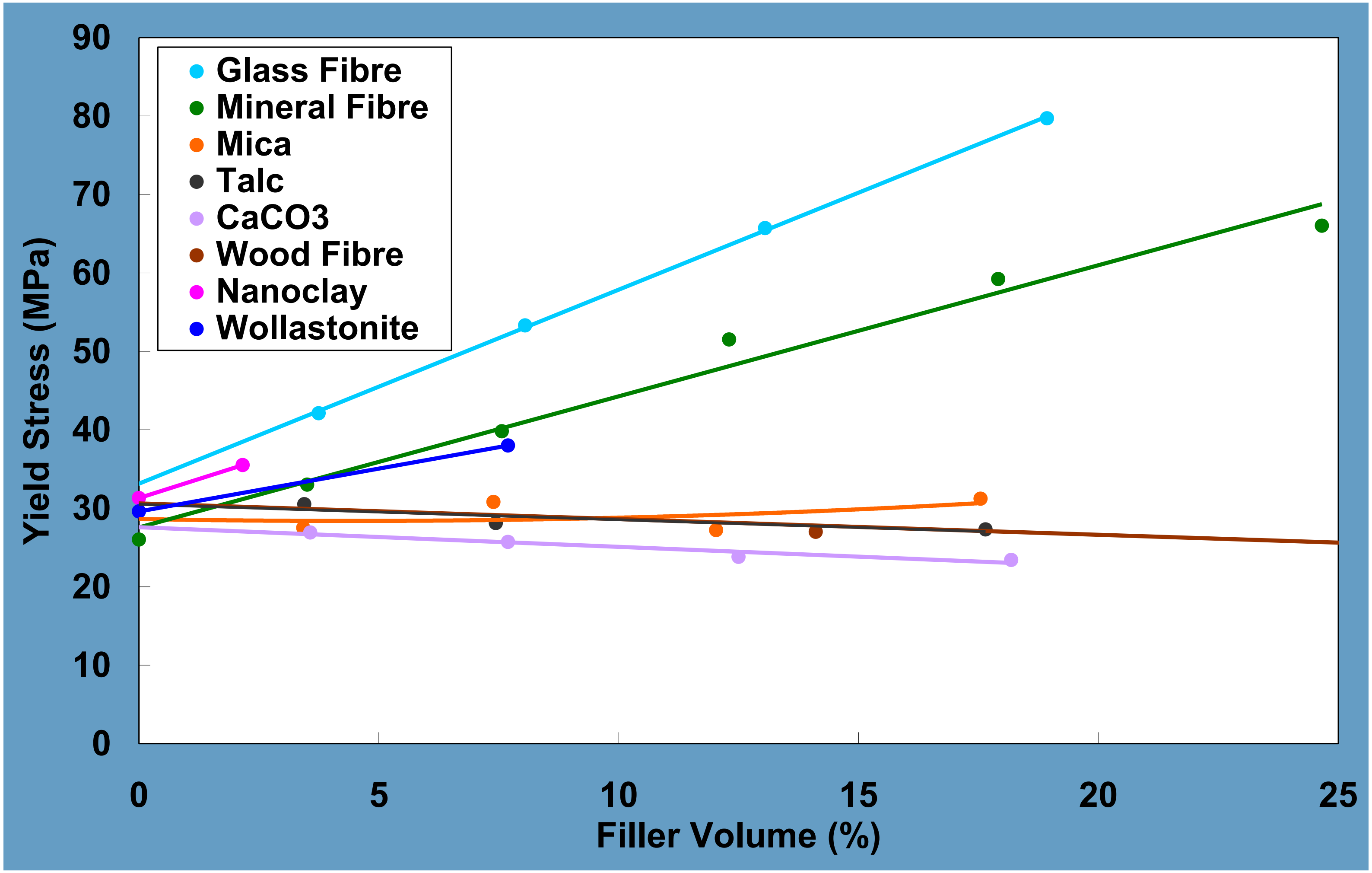
Anisotropic fillers can improve yield strength

High aspect ratio is best



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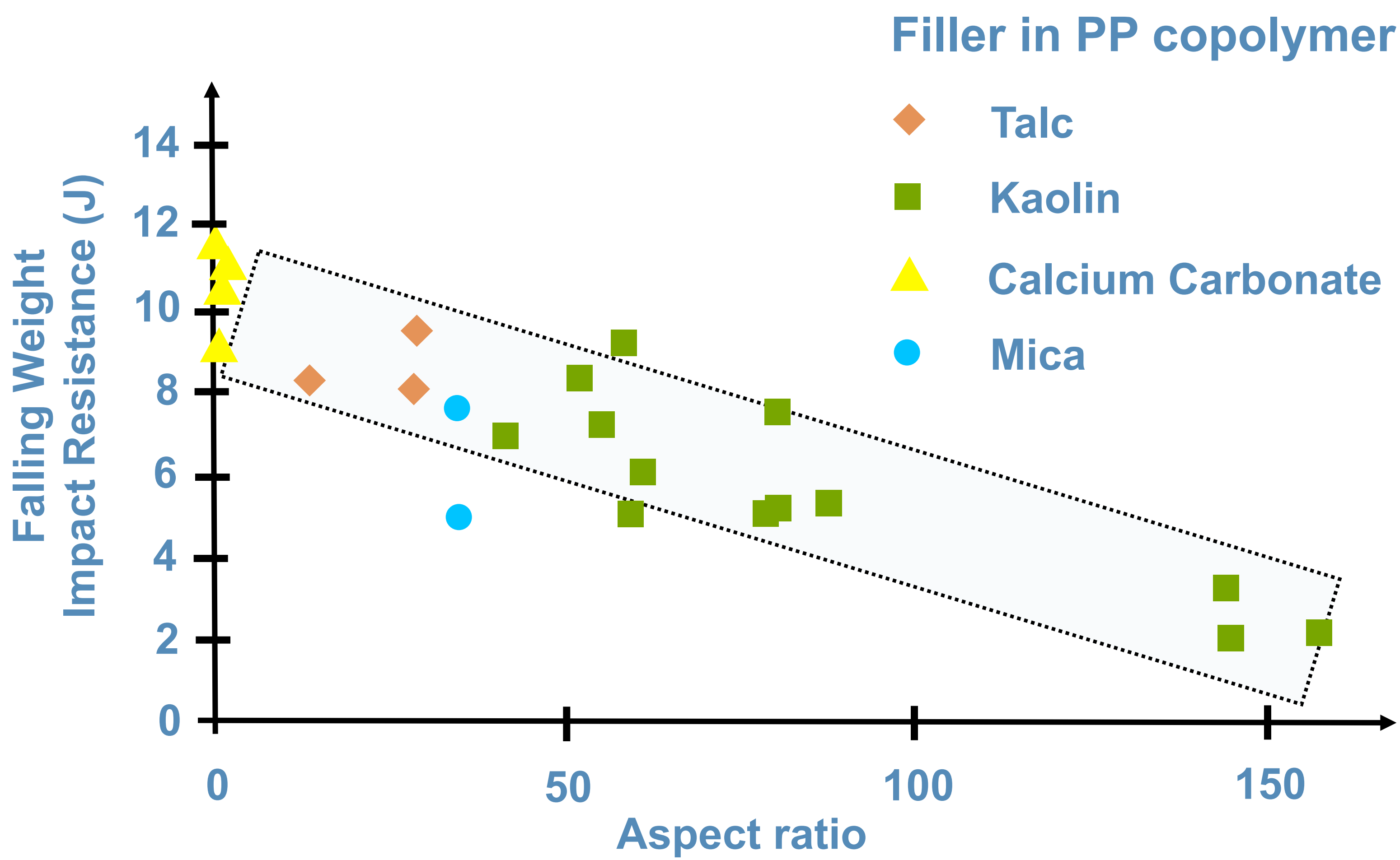
Aspect ratio & impact resistance

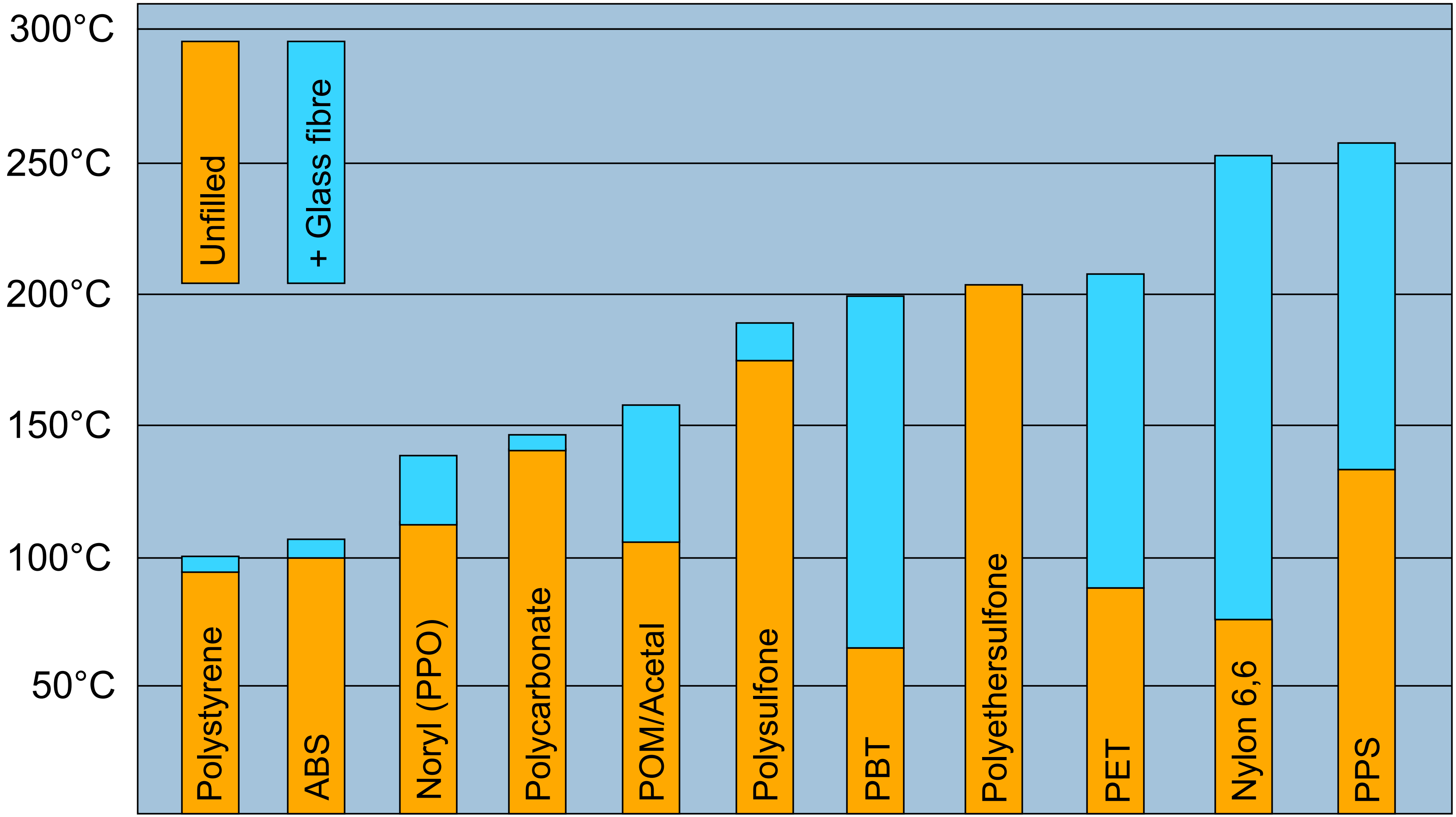
Anisotropic fillers worse for impact resistance



Courtesy of Imerys

Influence of glass fibre on HDT/B

Fillers very effective but only in semi-crystalline polymers



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Cheat sheet

How to modify the properties of composites

Property	Isotropic	Platy	Fibres
Modulus	↑	↑↑	↑↑↑
Yield Strength	–	↑	↑↑
HDT in amorphous polymer	–	–	–
HDT in semi x-line polymer	↑	↑↑	↑↑↑
Impact resistance	↑ or ↓	↓	↓
Elongation to break	↓	↓↓	↓↓↓
Permeability	↓	↓↓	↓

- Adding dispersant improves impact resistance, elongation, gloss & flow but modulus & yield strength unchanged
- Adding coupling agent will improve yield strength but not modulus, flow may worsen
- Adding impact modifier particles will improve impact resistance but will lower modulus, yield strength and flow
- Isotropic fillers work in all three directions equally
- Platy fillers are very good in two directions and fair in the other
- Fibers are very good in one direction and fair in the other two

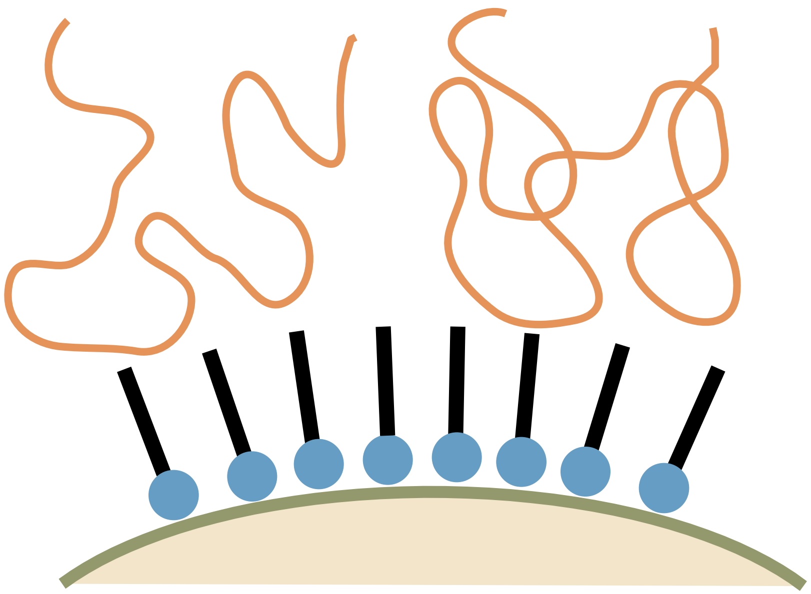
Fallacies

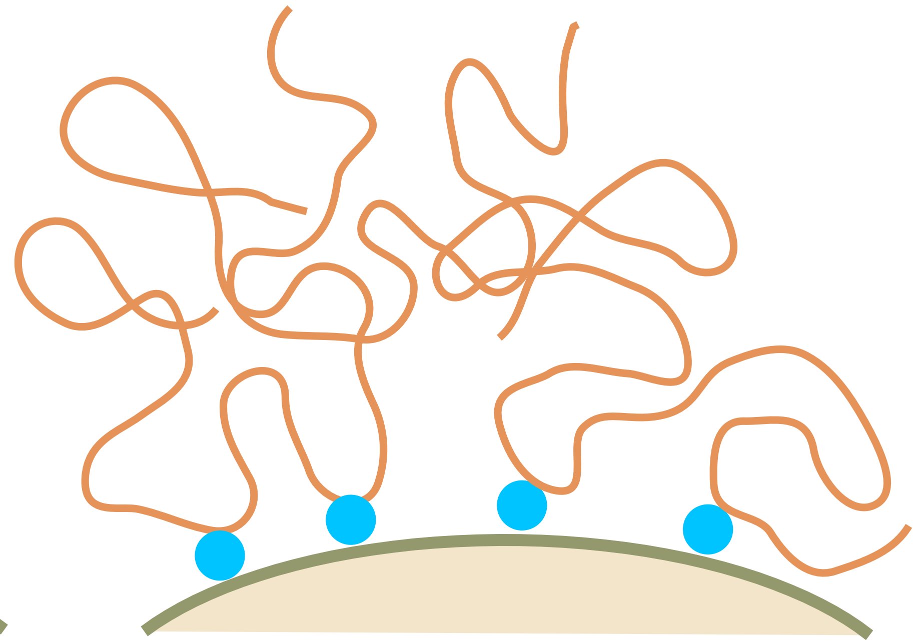
Some common misconceptions

- MFI is a good indicator flow
- Coupling agents always couple
- Coupling increases modulus
- Anisotropic fillers are better
- Properties depend on weight % filler
- Filler reduce the specific heat capacity of polymers
- Nano-composites are new
- Impact strength is a valid term
- Impact resistance is an intrinsic property
- Notched impact resistance is most meaningful
- Fillers function is just to reduce cost

Surface treatment types

Dispersants improve impact resistance: coupling agents for strength





Dispersant	**Coupling Agent**
A --- B	A --- B --- C
Anchor --- **B**uffer	**A**nchor --- **B**uffer --- **C**ouplant

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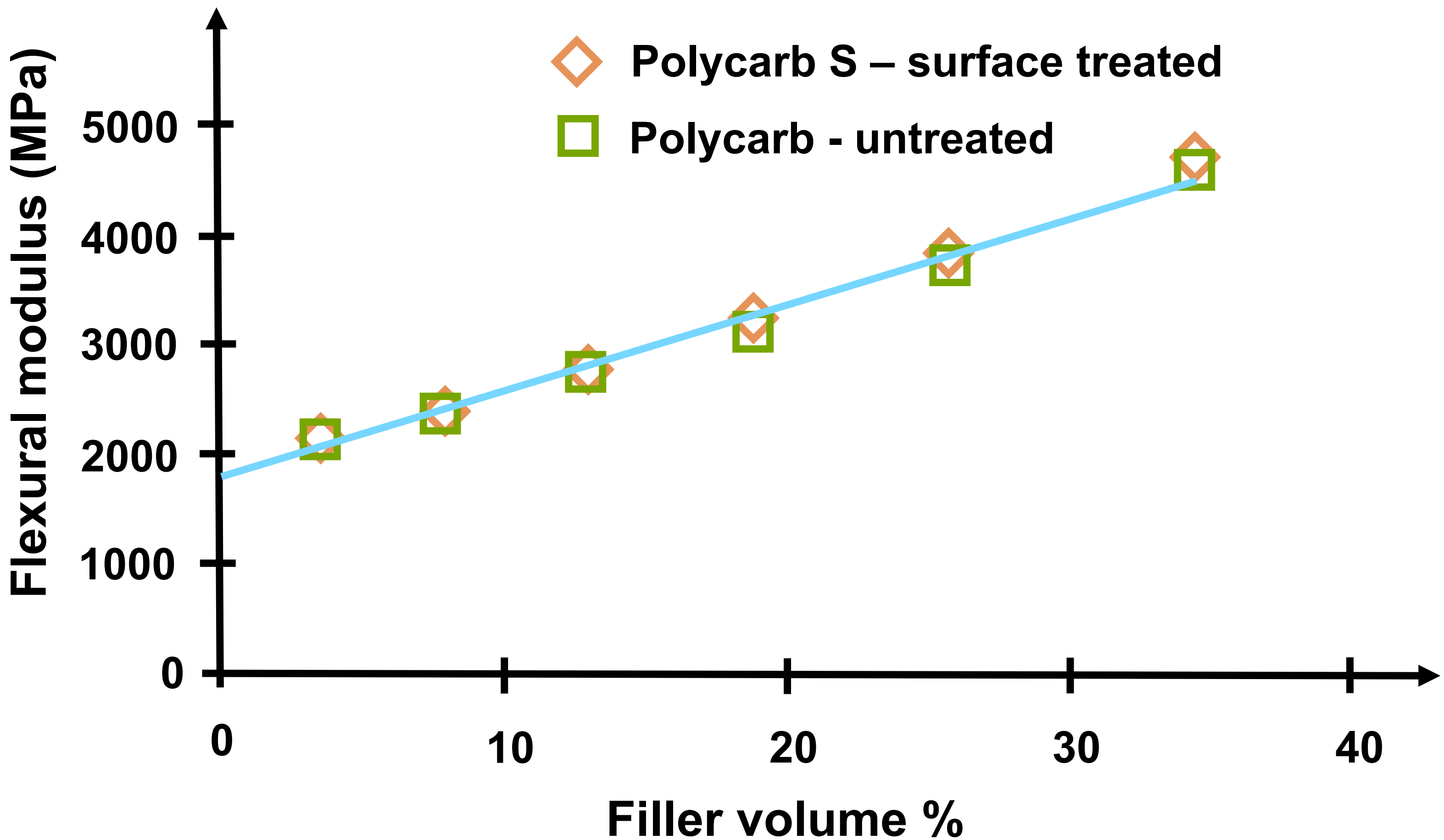
Anchor group filler specificity

Succinic anhydride is a very effective anchor group

Filler Type	Best Dispersant	2nd Best	3rd Best
Calcium Carbonate	**Succinic anhydride**	Carboxylic acid	Primary amine
Dolomite	Sulfonic acid	Carboxylic acid	**Succinic anhydride**
Magnesium Hydroxide	**Succinic anhydride**	Trichlorosilane	Carboxylic acid
Mica	Primary amine	Trichlorosilane	Sulfonic acid
Talc	Trichlorosilane	---	---
Silica	Trichlorosilane	Sulfonic acid	**Succinic anhydride**
Wollastonite	Primary amine	**Succinic anhydride**	Carboxylic acid
Titanium dioxide	**Succinic anhydride**	Carboxylic acid	Trichlorosilane

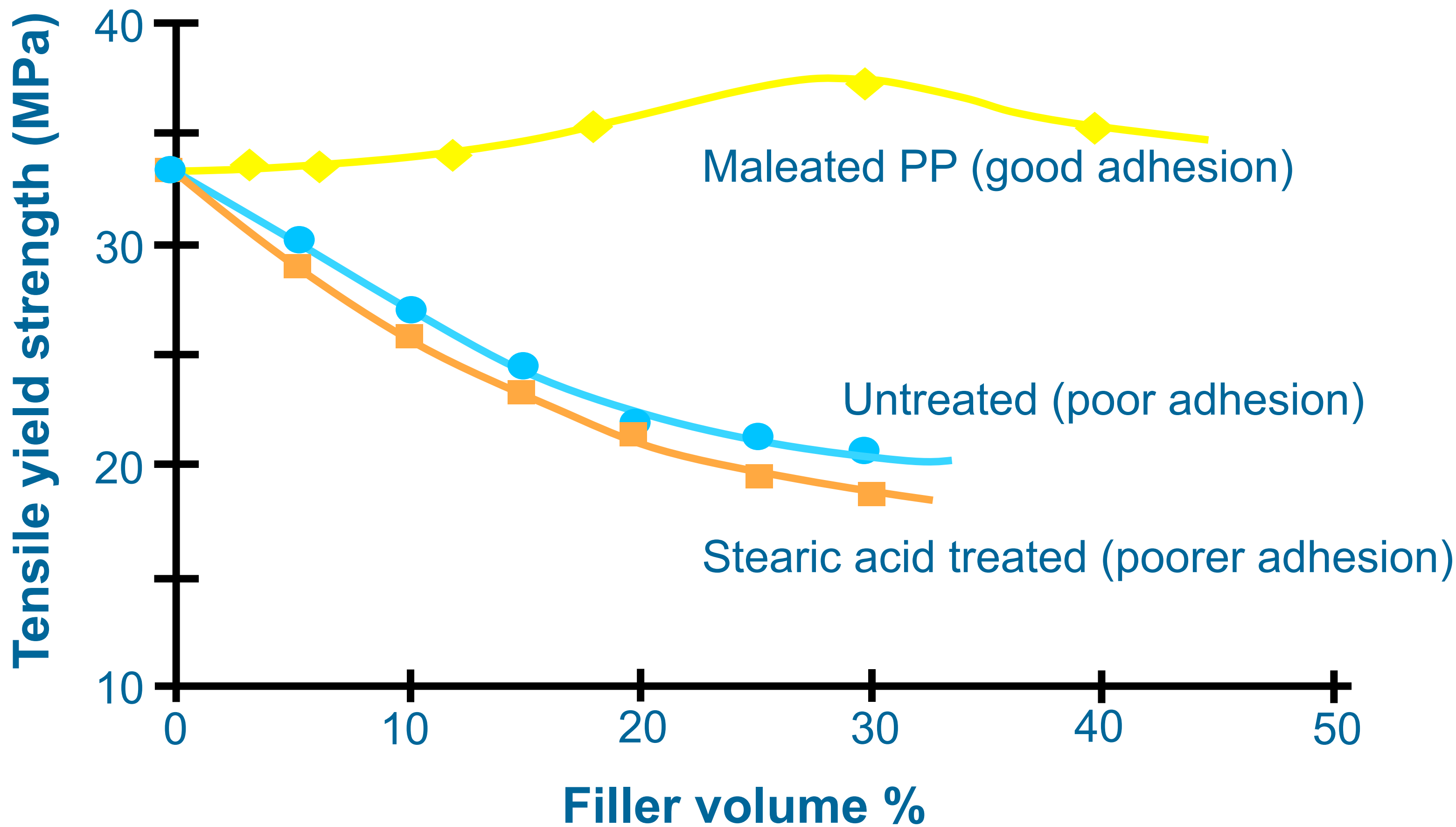
Coupling agents and modulus

Coupling and modulus – bonding does not affect modulus



Courtesy of Imerys

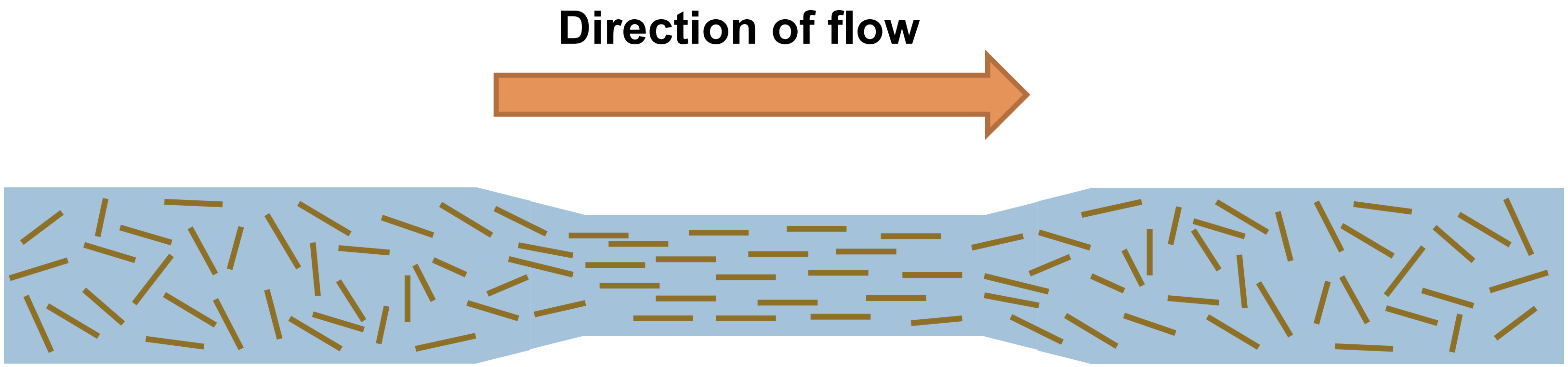
Coupling and yield strength – coupling agents raise yield strength



B. Pukánsky in Polypropylene Stucture, blends & composites vol 3

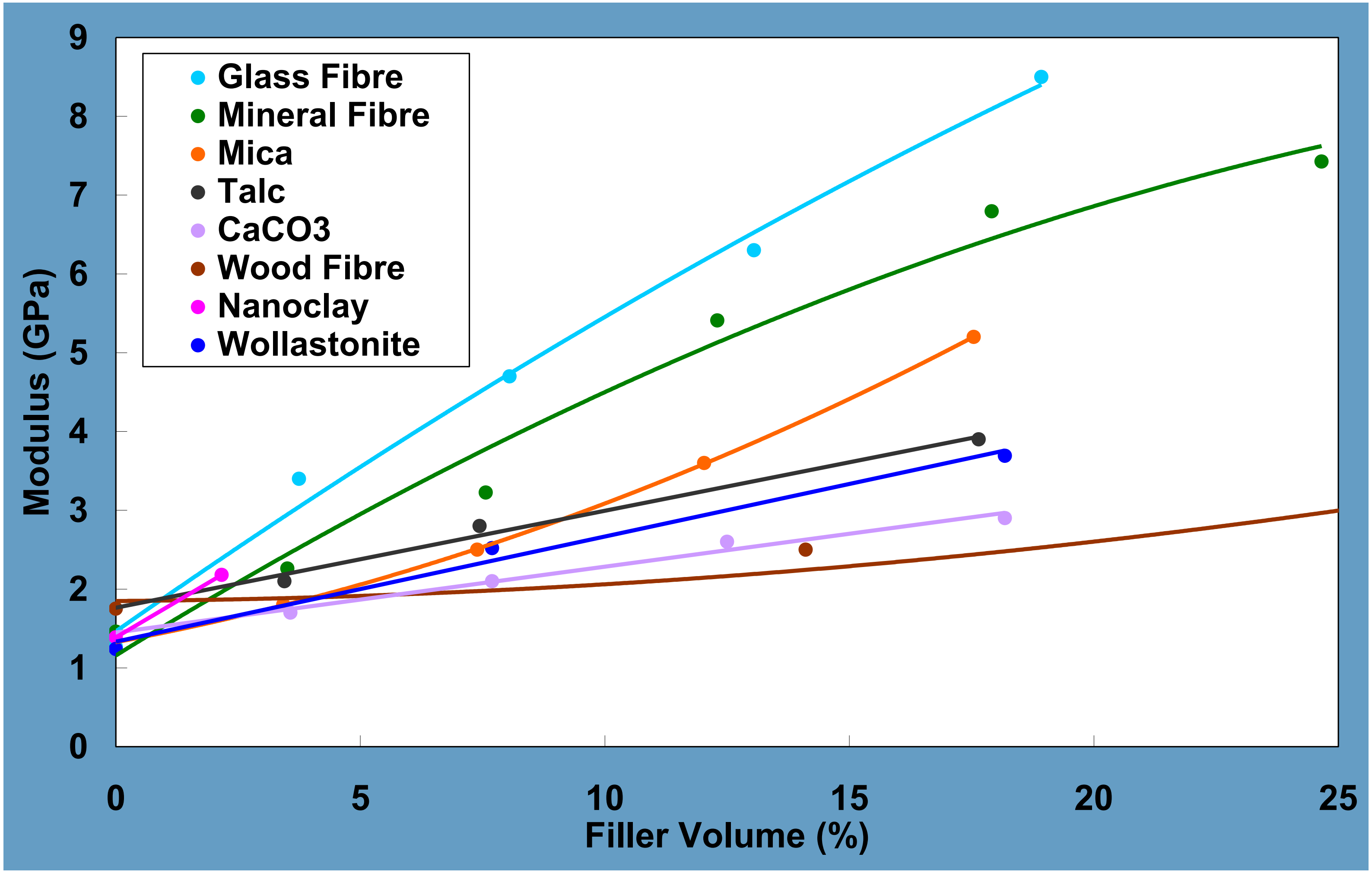
Effect of flow

Fibres and flakes align to give high tensile strength and modulus



Fillers improve modulus

High aspect ratio is best



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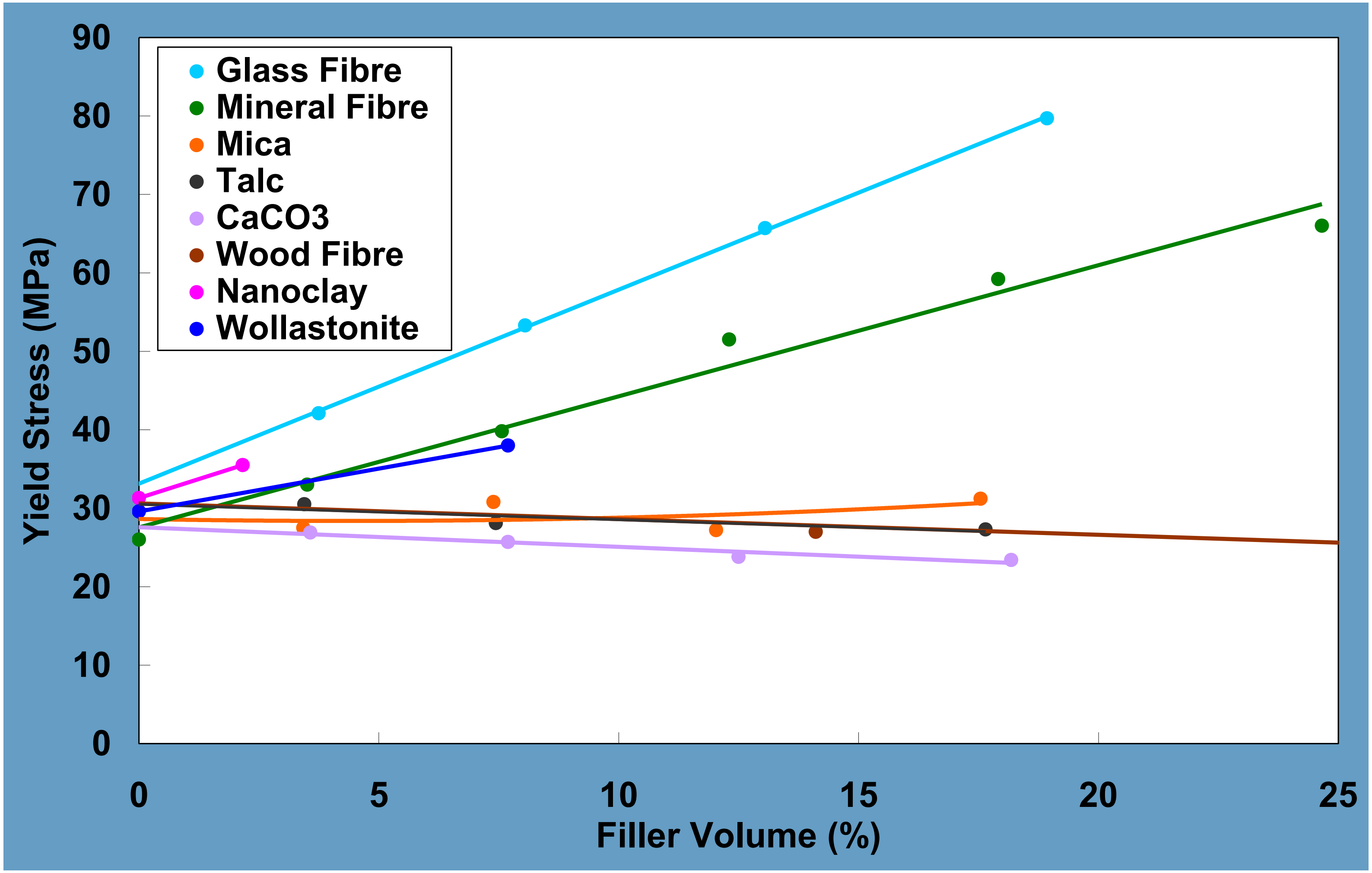
Anisotropic fillers can improve yield strength

High aspect ratio is best



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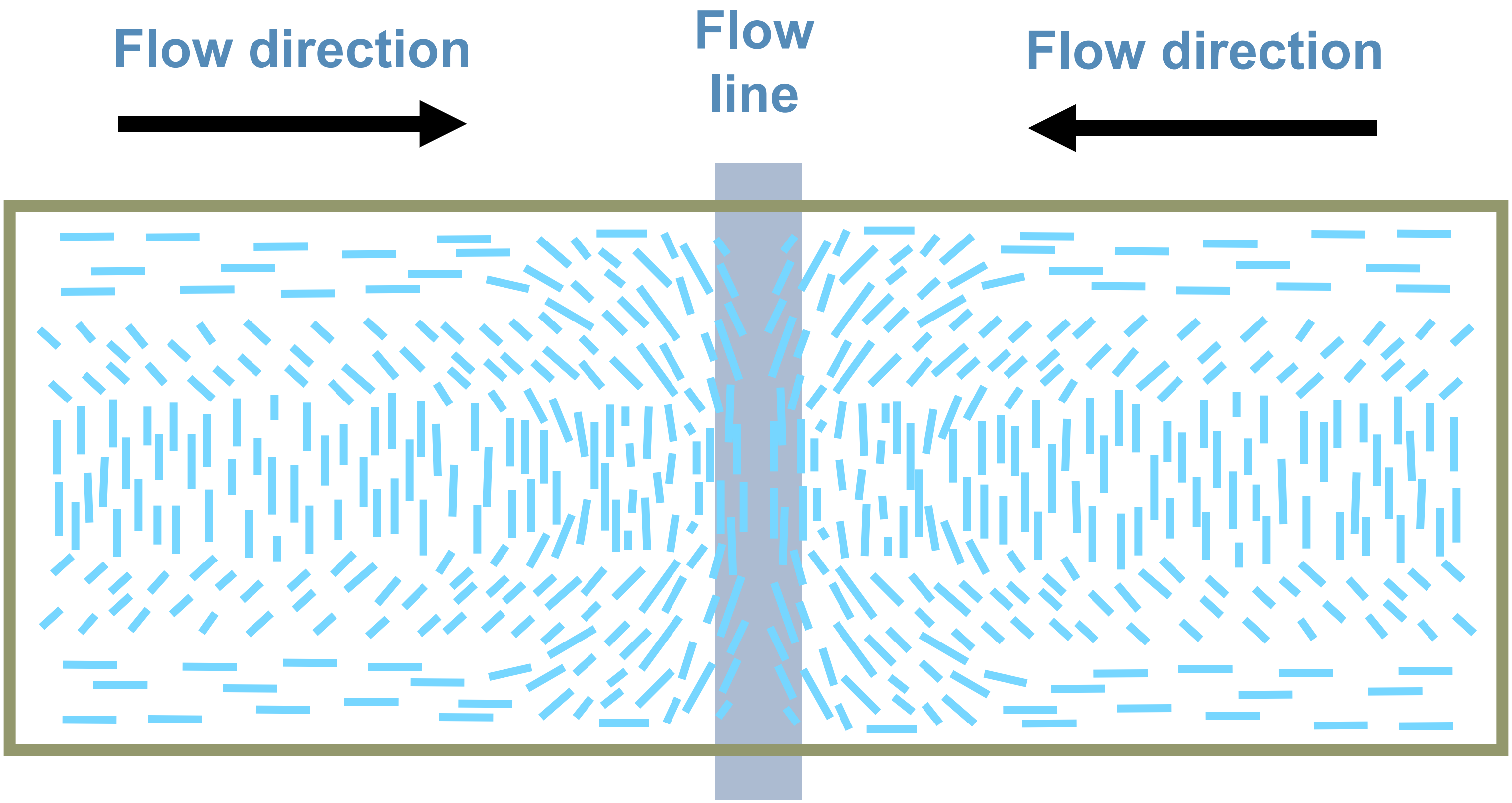
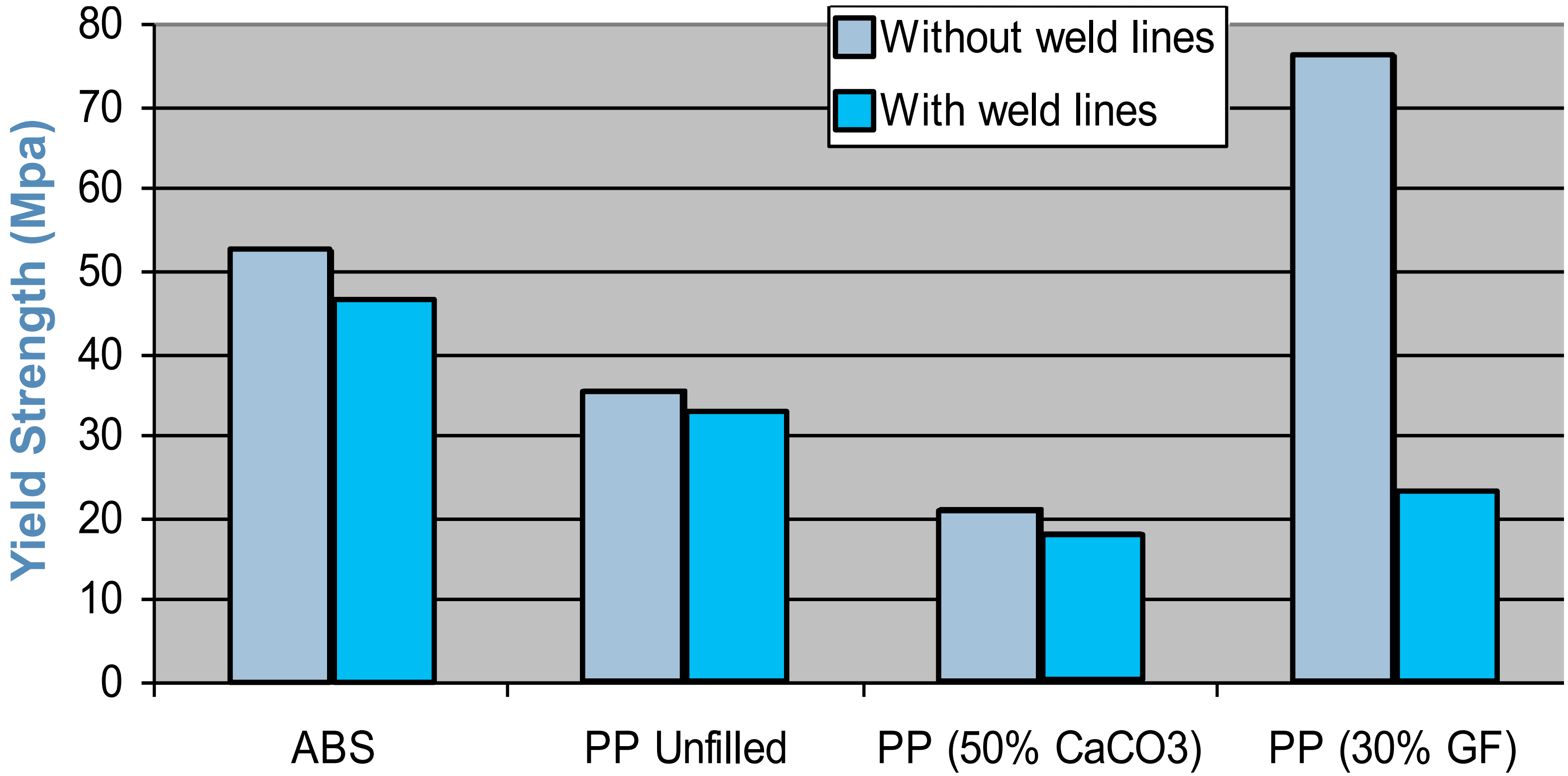
Weld / flow lines

Fillers give weld lines – weak points that cause failure



Fillers and weld line strength

More anisotropic fillers give lower weld line strength



Courtesy of Electrolux

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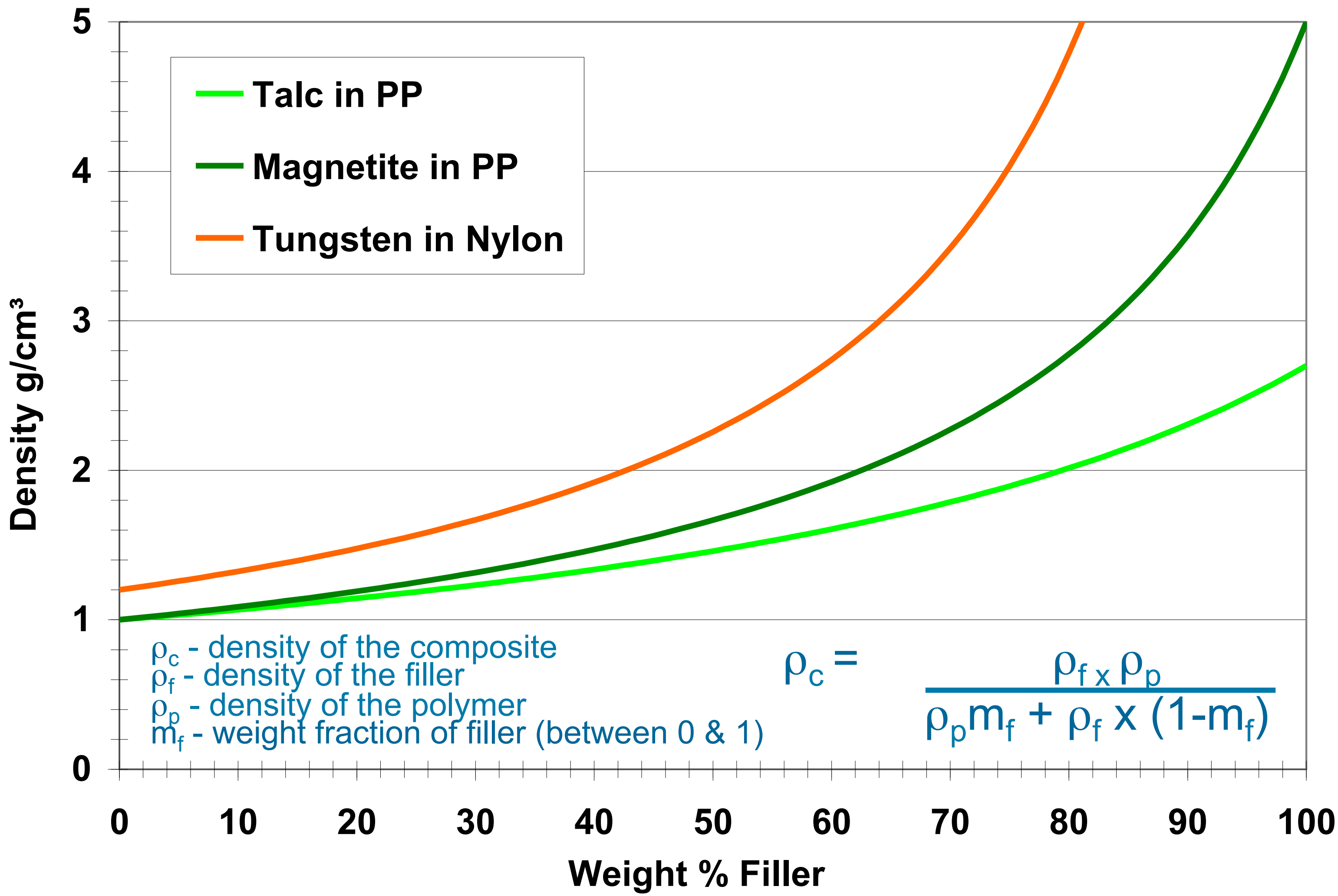
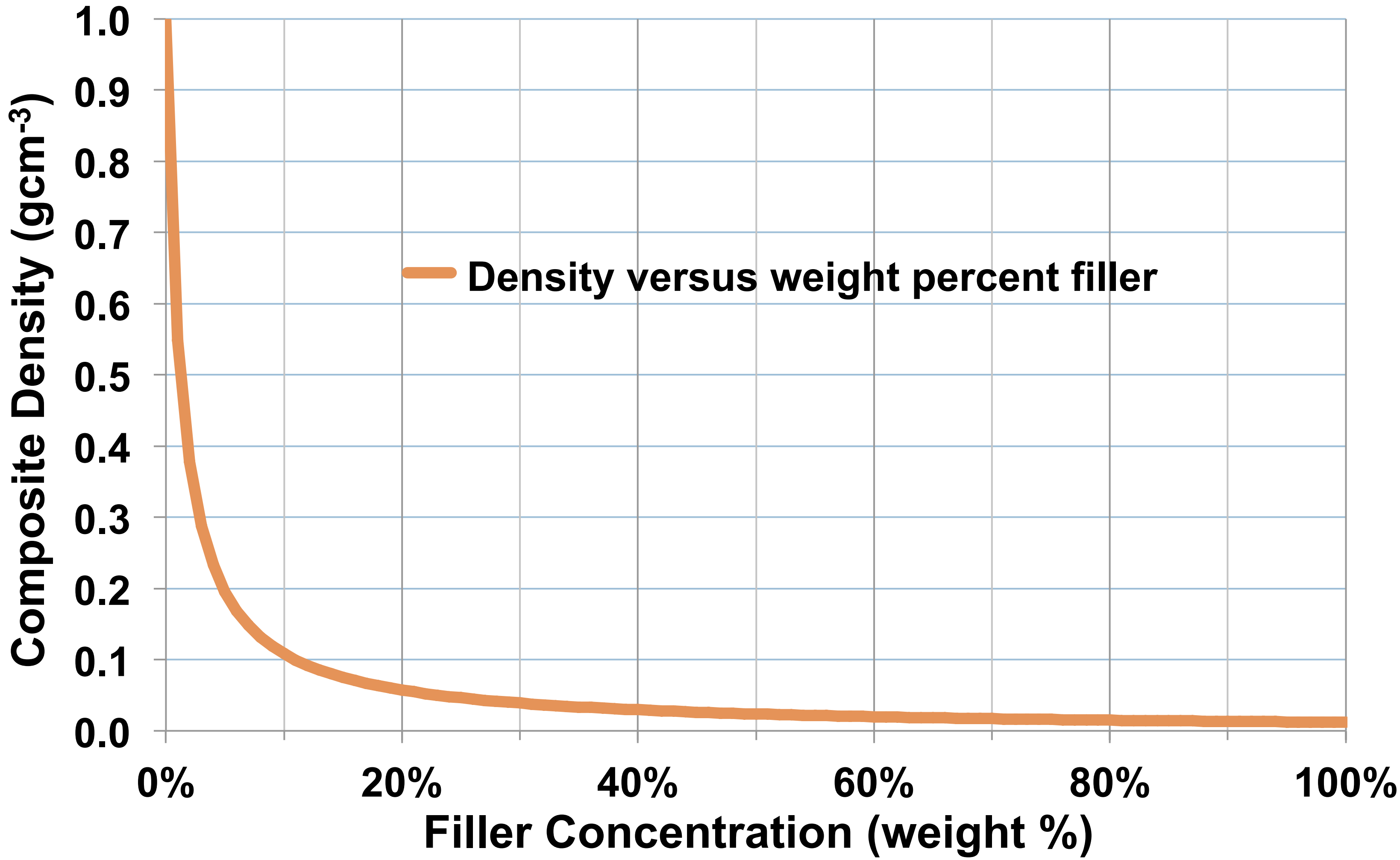
Composite density and filler loading

Always plot properties versus volume % filler to get straight lines!



Density versus weight % air as a filler

1 weight % air halves the mass of the material



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Volume specific heat capacity of polymers

Average is 2.1 kJ / litre.K

Polymer	Melt Density (gcm^{-3})	Mass Specific Heat of melt (kJ/kg.K)	Volume Specific Heat (kJ/litre.K)
PES	1.48	1.3	1.9
PVC-U	1.15	1.5	1.7
PET	1.15	1.6	1.8
Polystyrene	0.88	1.8	1.6
Polycarbonate	1.01	1.8	1.8
SAN	0.92	1.9	1.7
PMMA	1.01	2.0	2.0
PPO	0.92	2.0	1.8
ABS	0.89	2.1	1.9
PBT	1.12	2.1	2.4
Acetal / POM	1.22	2.5	3.1
PA 6	0.95	2.7	2.6
PA 6,6	0.97	2.7	2.6
PP	0.85	2.7	2.3
LDPE	0.79	3.2	2.5
HDPE	0.81	3.2	2.6
Aramid Fibers*	1.45	1.42	2.1
Average	---	---	**2.1**

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Source: Polypropylene The Definitive User's Guide and Databook except *Handbook of Fillers

Volume specific heat capacity of mineral and metallic fillers

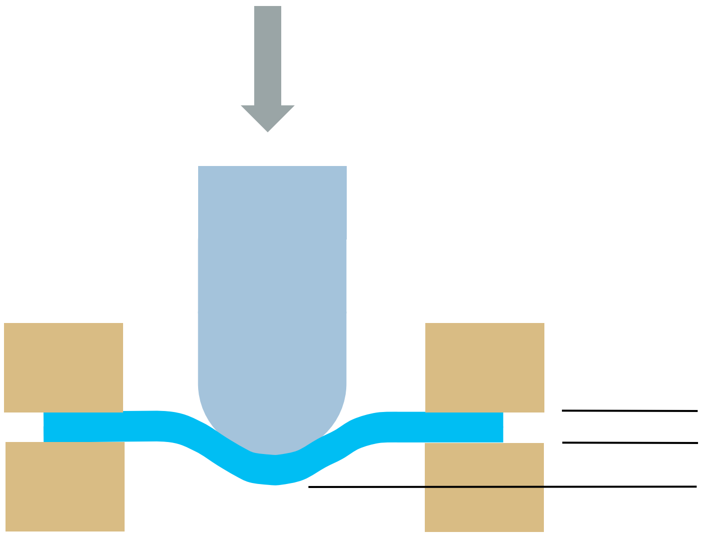
Average is 2.1 kJ / litre.K

Mineral or Metal	Density (gcm^{-3})	Mass Specific Heat (kJ/kg.K)	Volume Specific Heat (kJ/litre.K)
BN (hexagonal)	2.25	0.794	1.8
Quartz	2.65	0.8	2.1
Silver	10.5	0.188	2.0
Talc	2.75	0.82	2.3
Tungsten	19.35	0.088	1.7
Beryllium Oxide	2.85	1.03	2.9
Average	---	---	**2.1**

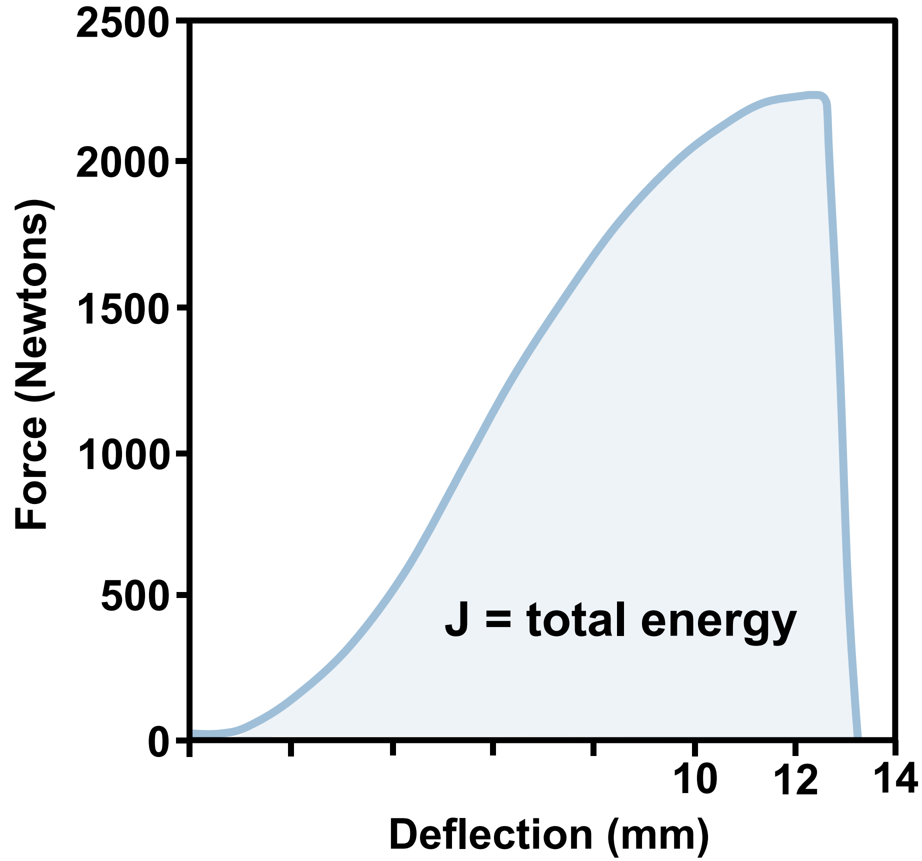
Source: Handbook of Fillers

Penetration test

Impact resistance is an energy (area under the curve) not a strength

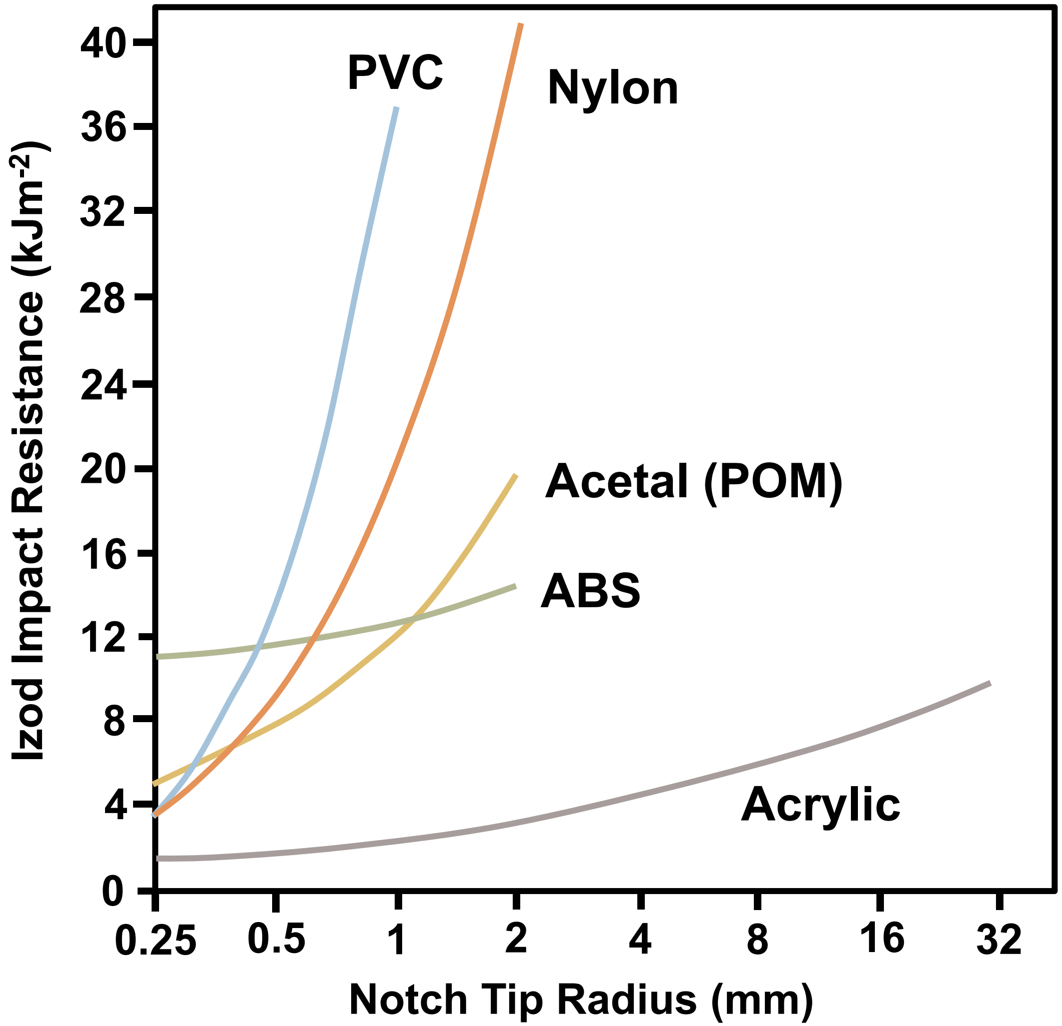


Standard velocity 4.4 ms^{-1}



Notch radius sensitivity

Take impact resistance results in context and with a grain of salt



VINCENT, P. I .
Impact Tests and Service Performance of Plastics, Plastics Institute, London (1971).

PC 3mm 8.6J, 6mm 1.6J so suppliers only show thin specimen results

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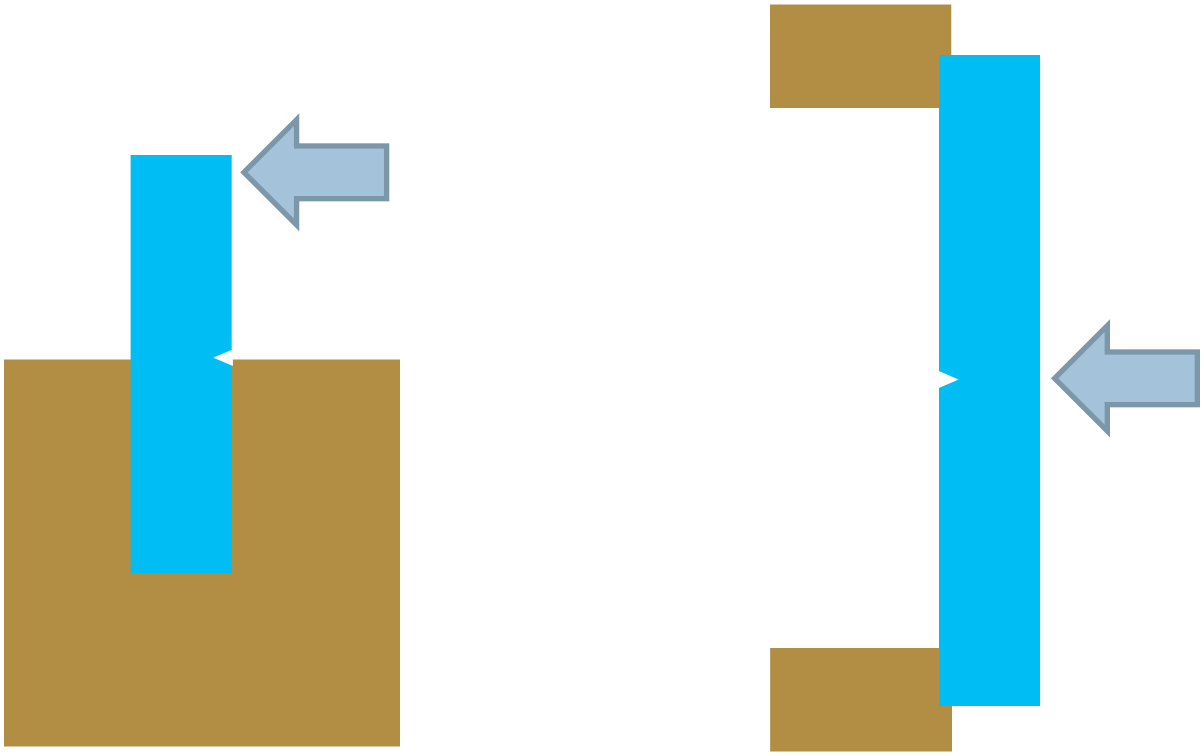
Impact test methodology

The notch provides crack initiation and helps consistency



Notched Izod

Notched Charpy

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$CaCO_3$ – particle size & cost

Prices must be compared on a per unit volume basis

Cost Euro / ton	Cost Euro / litre	Size $CaCO_3$ d_{50} microns
100	0.27	~ 2
200	0.54	~ 1
300	0.81	~ 0.5
400	1.08	~ 0.3
500	1.62	~ 0.1

Approximate Polymer prices € / L

PP 0.68

PE 0.74

PS 0.84

HIPS 0.85

PVC 0.98

PET 1.4

ABS 1.5

Nylon 2.7

PC 2.8

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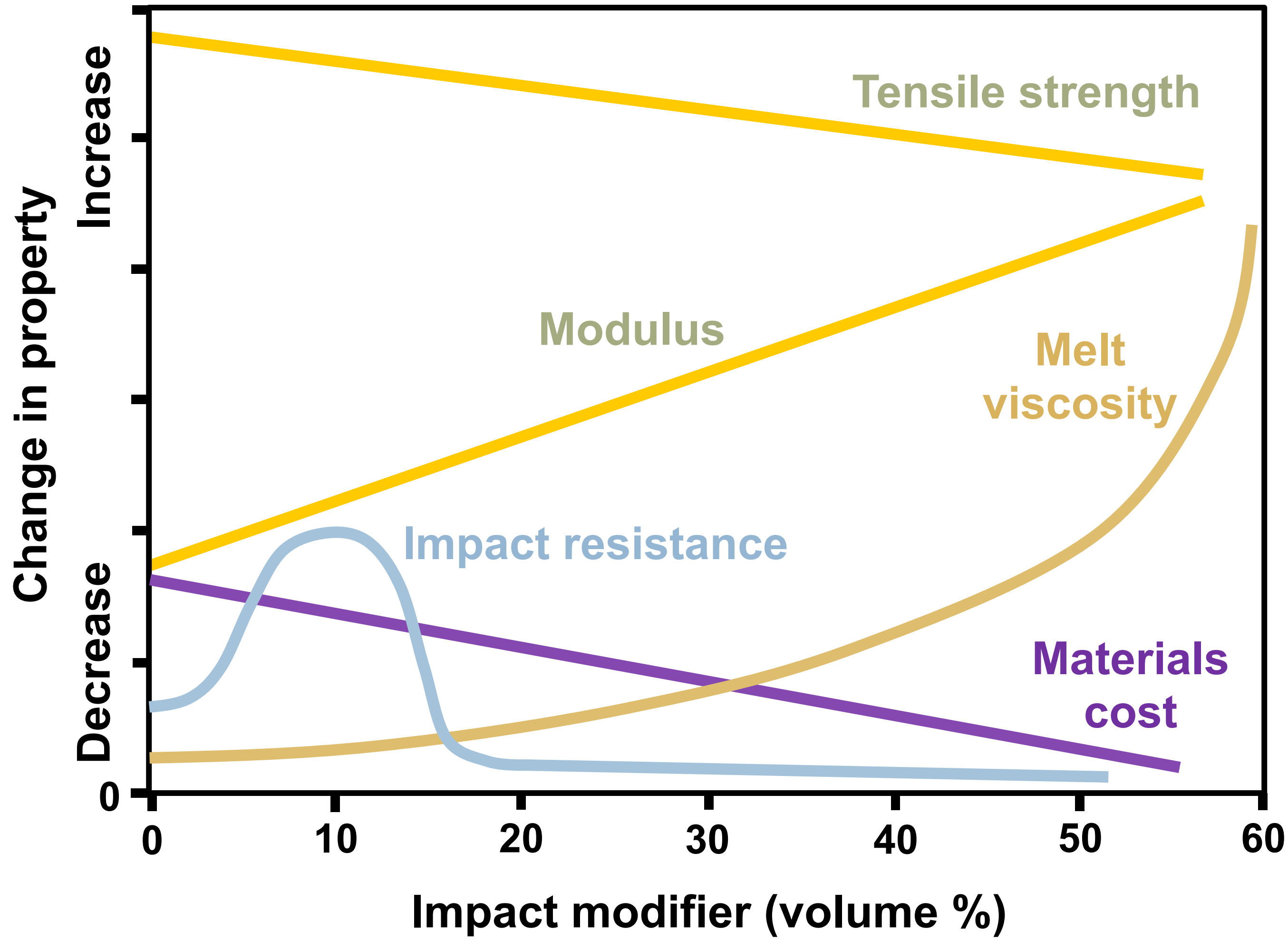
Filled polymers property profile

Fair impact resistance, higher stiffness, retained strength, lower cost



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Further reading

Some excellent resources I use every day

- Plastics Materials 7th Edition, J. A. Brydson, Butterworth-Heinemann 1999
- Plastics Additives Handbook, H. Zweifel, Hanser/Gardner, 2001
- Particulate-Filled Polymer Composites, 2nd Edition, Roger Rothon (Ed.), RAPRA, 2003
- Functional Fillers for Plastics, Marino Xanthos (Ed.), Wiley-VCH, 2005
- www.specialchem.com great resource for polymers, additives and more
- www.matweb.com free searcheable polymer properties data
- www.eng-tips.com free polymer & composites advice
- www.phantomplastics.com consultancy services – new materials, additives, training and problem solving

Thanks!