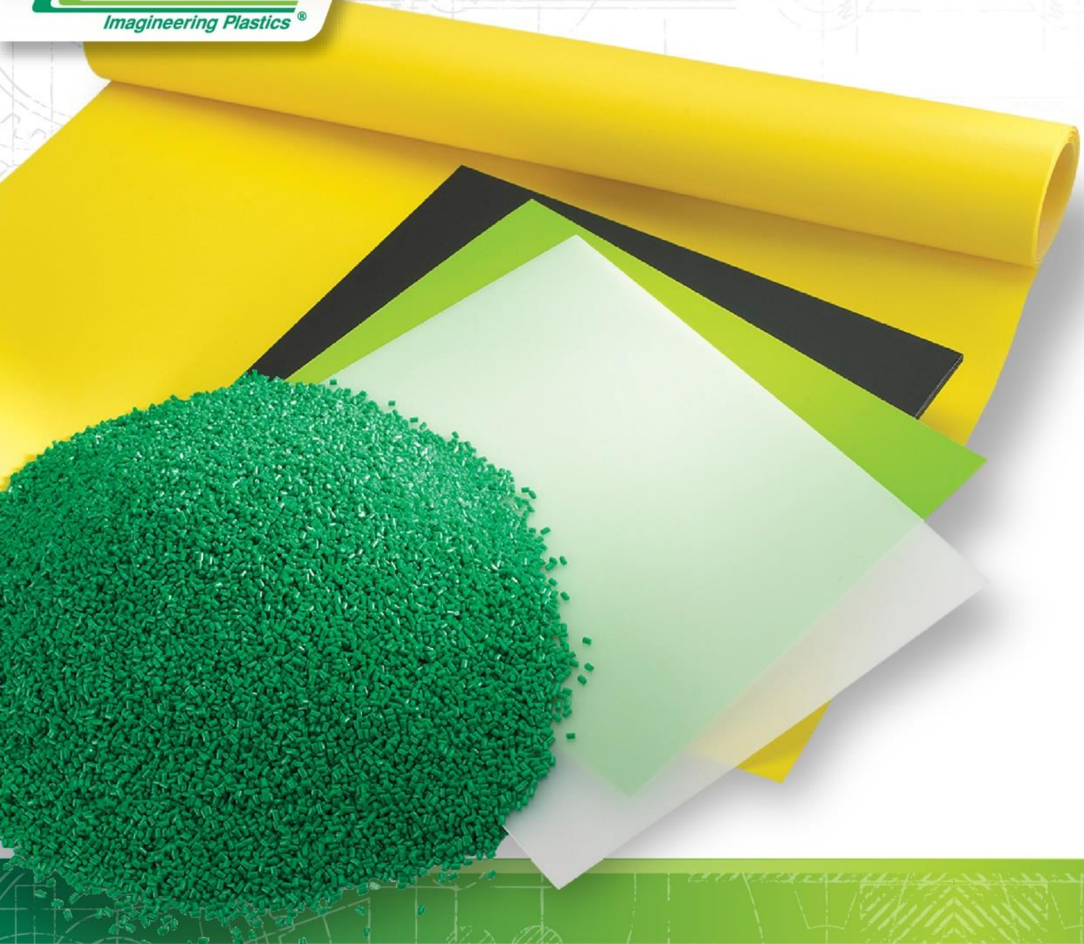
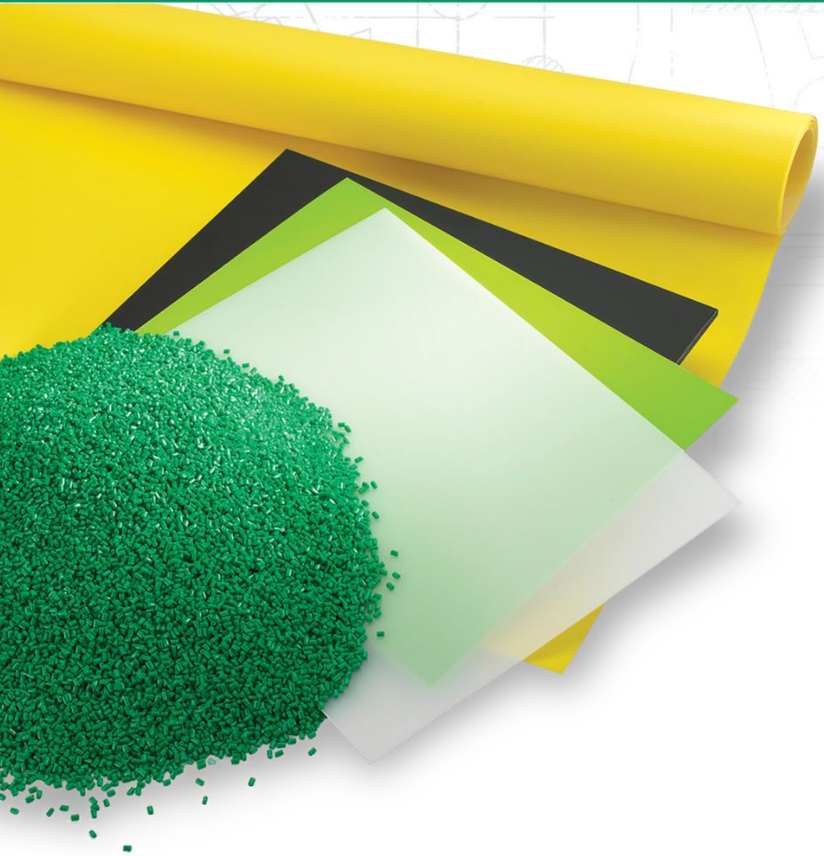


An Engineer’s Guide
to Specifying the Right Thermoplastic

Mark Bennick
Global Technology Manager



AGENDA

1. Define compounding
2. Plastic resin selection process
3. Application case studies
4. Compounding to enhance performance
5. New RTP Company technologies

INDEPENDENT SPECIALTY COMPOUNDER

Compounder → We blend thermoplastic resins with fillers, additives, and modifiers

Specialty → We create engineered formulations

Independent → We are unbiased in our selection of raw materials

THE COMPOUNDING PROCESS

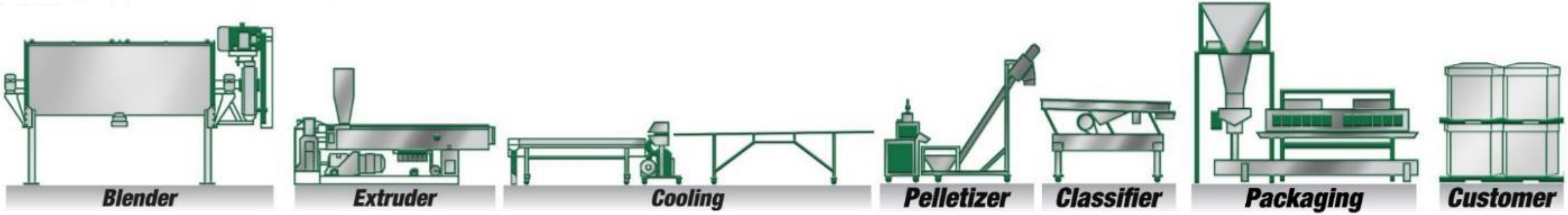
Base resin

Glass fiber

Blue pigment

Raw Materials

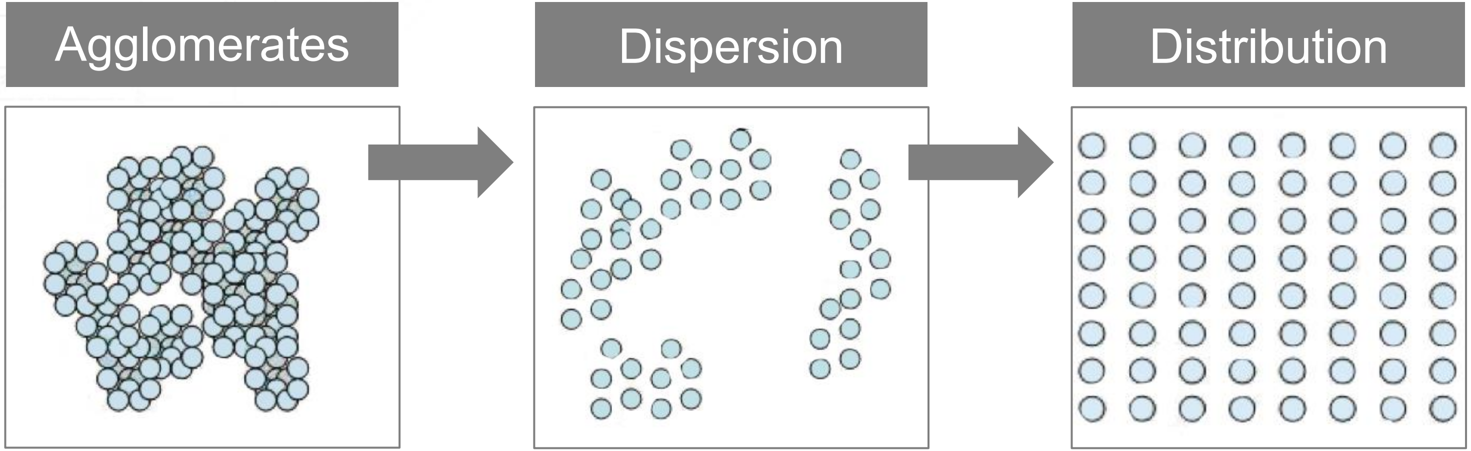
Finished Product



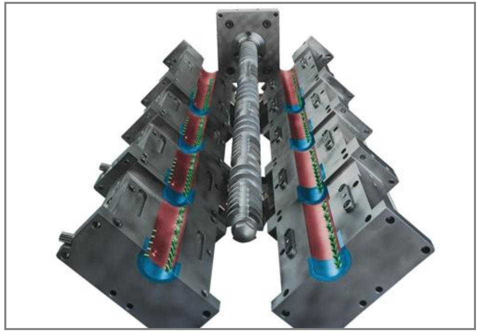
COMPOUNDING OBJECTIVES

Mixing

- Dispersive
- Distributive



COMPOUNDING EXTRUDERS

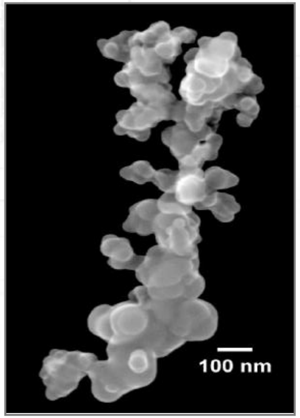


Single Screw

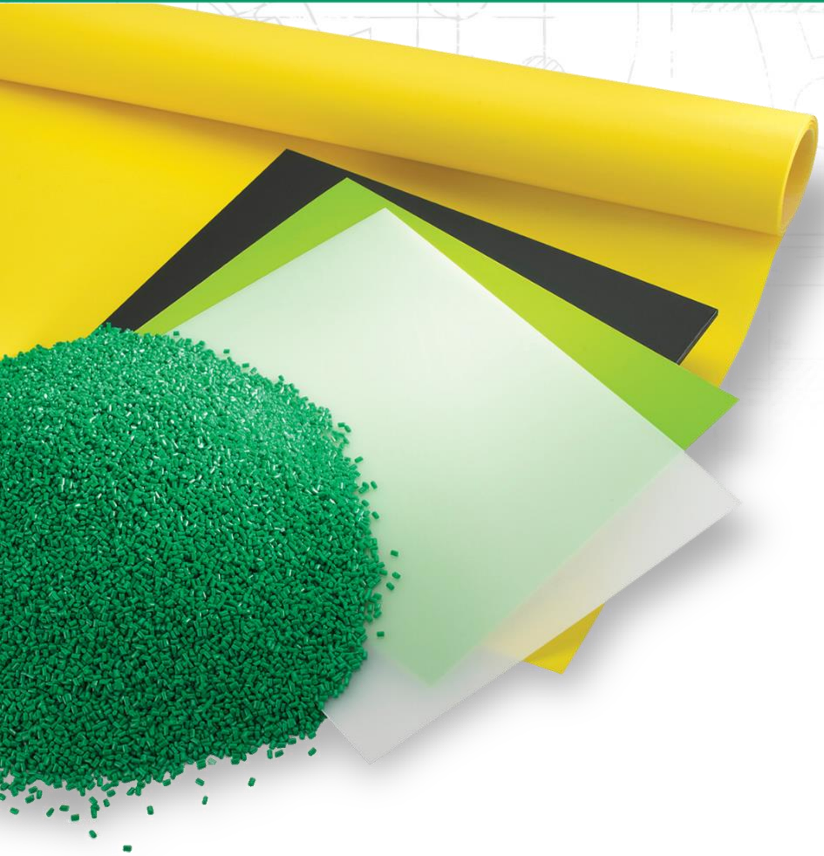
Twin Screw

Co-Kneader

PUTTING COMPOUNDING INTO PERSPECTIVE



- Conductive carbon black surface area = 130 m^2/gram
- 34 grams carbon black = surface area of football field (4460m^2)
- Dispersing a 20% carbon black compound is similar to evenly coating a football field with 136 grams of plastic!



Section 2:

PLASTIC RESIN SELECTION PROCESS

THE DILEMMA

60 thermoplastic resins + 100 additives
= 1000s of potential compounds

Which ONE do I choose for my application???

PLASTIC SELECTION PROCESS

Step 1: Use Resin Morphology

Step 2: Use Thermal and Cost Requirements

Step 3: Fine Tuning and Special Features

PLASTIC SELECTION PROCESS

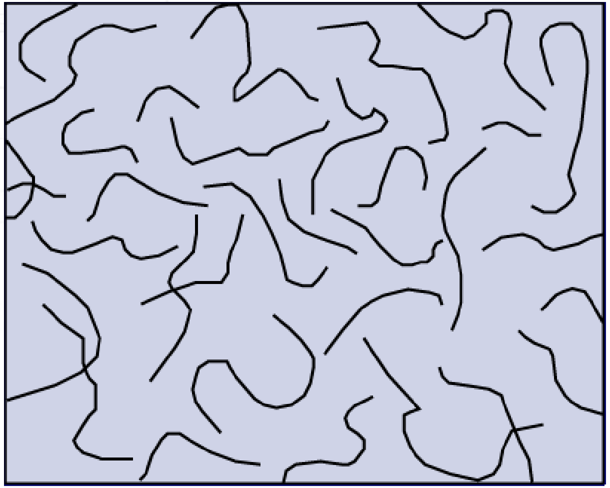
Step 1: Use Resin Morphology

Step 2: Use Thermal and Cost Requirements

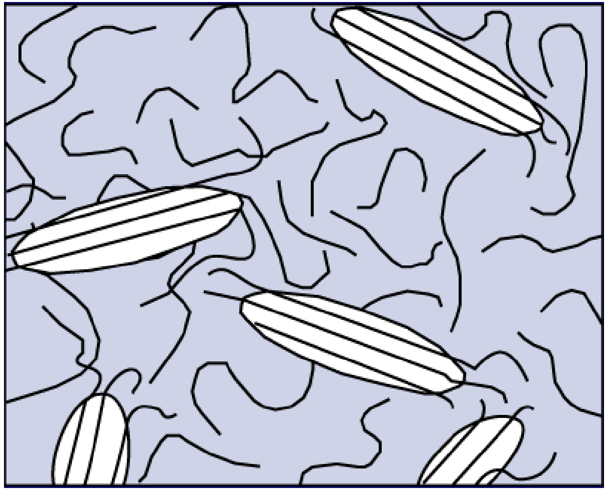
Step 3: Fine Tuning and Special Features

MORPHOLOGY

The form and structure the molecules of a polymer take upon solidification

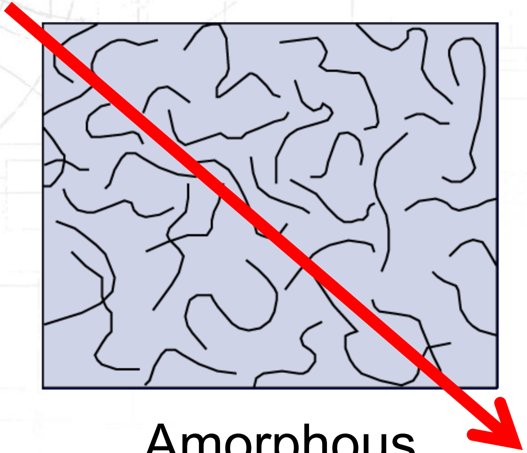


Amorphous

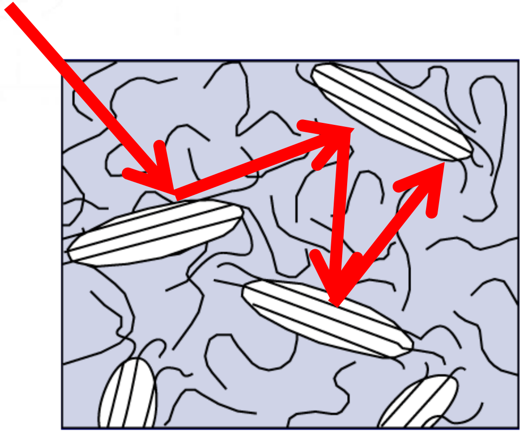


Semi-Crystalline

MORPHOLOGY



Amorphous

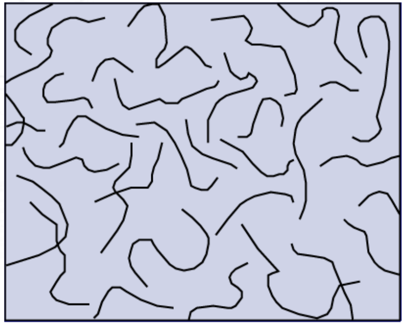


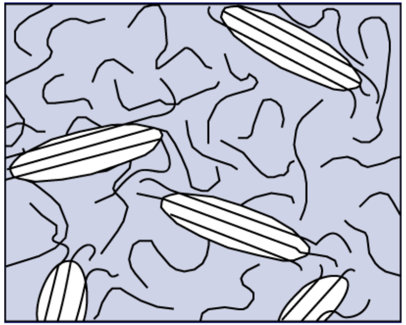
Semi-Crystalline

Compare

- Molecular packing (shrinkage)
- Resistance to molecular disentanglement (chemical/abrasion resistance)
- Melting characteristics (flow)
- Light refraction (opacity)

MORPHOLOGY CHARACTERISTICS





	Amorphous	Semi-Crystalline
Low Shrinkage	O	
Low Warpage	O	
Tight Tolerances	O	
Transparency	O	
Mold Flow Ease		O
Chemical Resistance		O
Wear Resistance		O

MORPHOLOGY CHARACTERISTICS

Lens?

Fuel Float?

Precision Printer Chassis?

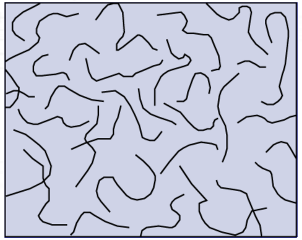
Tool Housing?

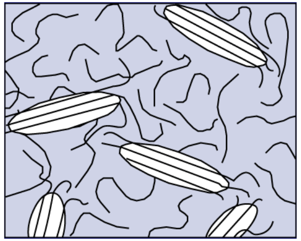
Multiple Pin Connectors?

Pulley?

Grease Fitting?

Laptop Cover?

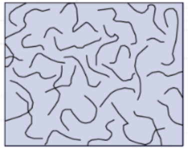




Amorphous	Semi-Crystalline	
O		Low Shrinkage
O		Low Warpage
O		Tight Tolerances
O		Transparency
	O	Mold Flow Ease
	O	Chemical Resistance
	O	Wear Resistance

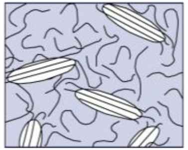
MORPHOLOGY OF THERMOPLASTICS

Amorphous



Polyetherimide (PEI)
Polyethersulfone (PES)
Polysulfone (PSU)
Amorphous Nylon
Polycarbonate (PC)
Acrylic (PMMA)
Acrylonitrile Butadiene Styrene (ABS)
Styrene Acrylonitrile (SAN)
High Impact Polystyrene (HIPS)
Polystyrene (PS)

Semi-Crystalline



Polyetheretherketone (PEEK)
Polyphenylene Sulfide (PPS)
Polyphthalamide (PPA)
Polyamide (PA/Nylons)
Polybutylene Terephthalate (PBT)
Polyethylene Terephthalate (PET)
Acetal (POM)
Polylactic Acid (PLA)
Polypropylene (PP)
Polyethylene (HDPE, LDPE, LLDPE)

PLASTIC SELECTION PROCESS

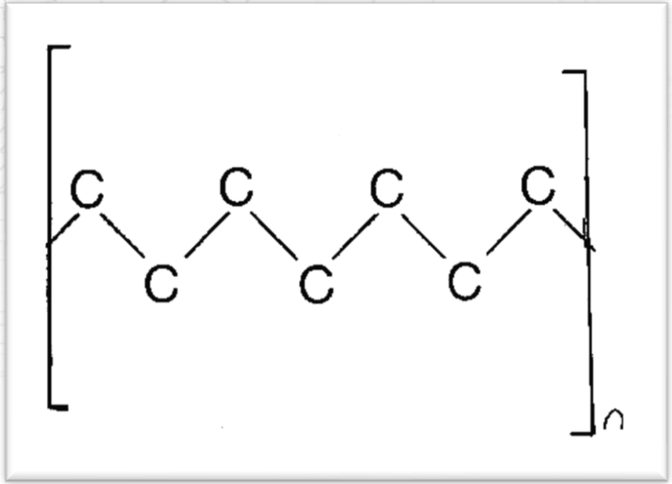
Step 1: Use Resin Morphology

Step 2: Use Thermal and Cost Requirements

Step 3: Fine Tuning and Special Features

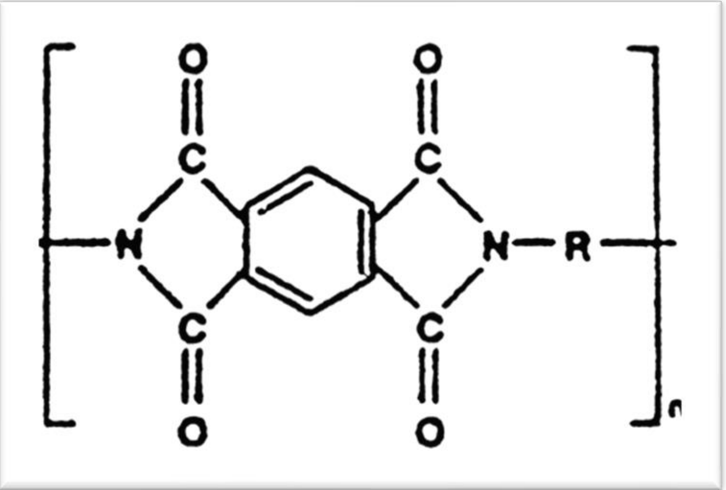
MORPHOLOGY AND STRUCTURE

Aliphatic Polymer Chain



Polyethylene (Tg -5 °F)

Aromatic Polymer Chain

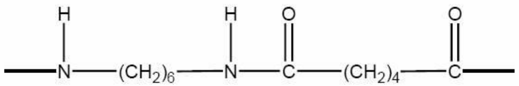


Polyimide (Tg 500 °F)

The truss structure and strong chemical bonds of aromatic polymer results in the high temperature performance and resistance to burning.

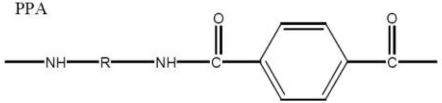
STRUCTURE OF SELECTED POLYMERS

Nylon 66



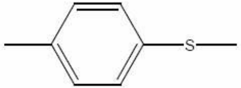
Tg = 60 °C Tm = 265 °C

PPA



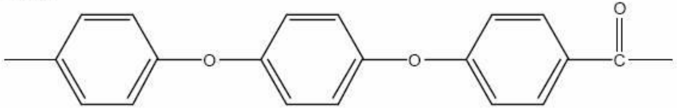
Tg = 132 °C Tm = 325 °C

PPS



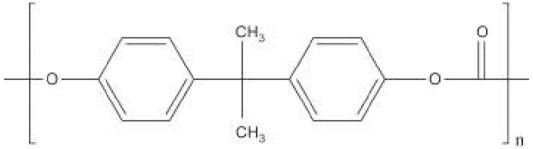
Tg = 95 °C Tm = 287 °C

PEEK



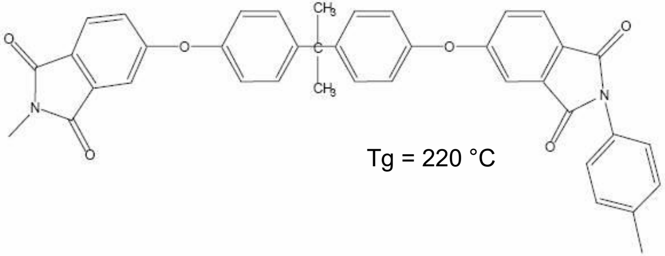
Tg = 149 °C Tm = 340 °C

Polycarbonate



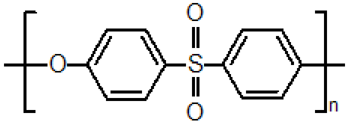
Tg = 148 °C

Polyetherimide



Tg = 220 °C

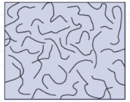
PES



Tg = 230 °C

MORPHOLOGY OF THERMOPLASTICS VS. THERMAL/COST

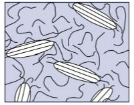
Amorphous



- Polyetherimide (PEI)
- Polyethersulfone (PES)
- Polysulfone (PSU)
- Amorphous Nylon
- Polycarbonate (PC)
- Acrylic (PMMA)
- Acrylonitrile Butadiene Styrene (ABS)
- Styrene Acrylonitrile (SAN)
- High Impact Polystyrene (HIPS)
- Polystyrene (PS)

Thermal and Cost Increases

Semi-Crystalline



- Polyetheretherketone (PEEK)
- Polyphenylene Sulfide (PPS)
- Polyphthalamide (PPA)
- Polyamide (PA/Nylons)
- Polybutylene Terephthalate (PBT)
- Polyethylene Terephthalate (PET)
- Acetal (POM)
- Polylactic Acid (PLA)
- Polypropylene (PP)
- Polyethylene (HDPE, LDPE, LLDPE)

Commodity (<$1.50) • Engineered ($1.50-$4.00) • High Performance (>$4.00)

PLASTIC SELECTION PROCESS

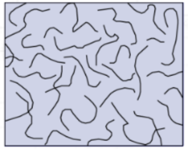
Step 1: Use Resin Morphology

Step 2: Use Thermal and Cost Requirements

Step 3: Fine Tuning and Special Features

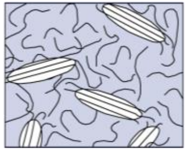
ENGINEERED & COMMODITY RESINS

Amorphous



Amorphous Nylon
Polycarbonate (PC)
Acrylic (PMMA)
Acrylonitrile Butadiene Styrene (ABS)
Styrene Acrylonitrile (SAN)
High Impact Polystyrene (HIPS)
Polystyrene (PS)

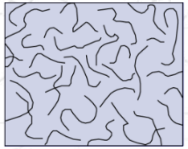
Semi-Crystalline



Polyamide (PA/Nylons)
Polybutylene Terephthalate (PBT)
Polyethylene Terephthalate (PET)
Acetal (POM)
Polylactic Acid (PLA)
Polypropylene (PP)
Polyethylene (HDPE, LDPE, LLDPE)

Commodity (<$1.50) • Engineered ($1.50-$4.00)

AMORPHOUS RESINS

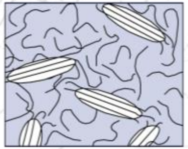


Morphology Features -- Low shrink, low warp, tight dimensional tolerances, transparent (except HIPS & ABS), poor chemical and abrasion resistance, poor flow in thin mold sections

Amorphous	Special Features
Amorphous Nylon	Transparent/good chem. resistance
Polycarbonate (PC)	Optical transparency/high impact
Acrylic (PMMA)	Optical transparency/UV stable
Acrylonitrile Butadiene Styrene (ABS)	High impact/high gloss/opaque
Styrene Acrylonitrile (SAN)	Transparent/mod. chem. resistance
High Impact Polystyrene (HIPS)	Moderate impact/opaque
Polystyrene (PS)	Transparent/brittle

Commodity (<\$1.50) • Engineered (\$1.50-\$4.00)

SEMI-CRYSTALLINE RESIN



Morphology Features -- Excellent chemical resistance, excellent abrasion resistance, good flow in thin mold sections, poor dimensions, opaque

Semi- Crystalline	Special Features
Nylon 6/12	Less sensitive to humidity vs. 6 & 6/6
Nylon 6/6	Better thermal vs. 6/humidity dep.
Nylon 6	Hides GF/strong but humidity dep.
Polybutylene Terephthalate (PBT)	Good electricals/easier to mold
Polyethylene Terephthalate (PET)	Good electricals/difficult to mold
Acetal (POM)	Low wear & friction/high fatigue
Polylactic Acid (PLA)	Green/Low impact & thermal
Polypropylene (PP)	Poor low temp impact/mod thermal
Polyethylene (HDPE, LDPE, LLDPE)	Good low temp impact

Commodity (<$1.50) • Engineered ($1.50-$4.00)

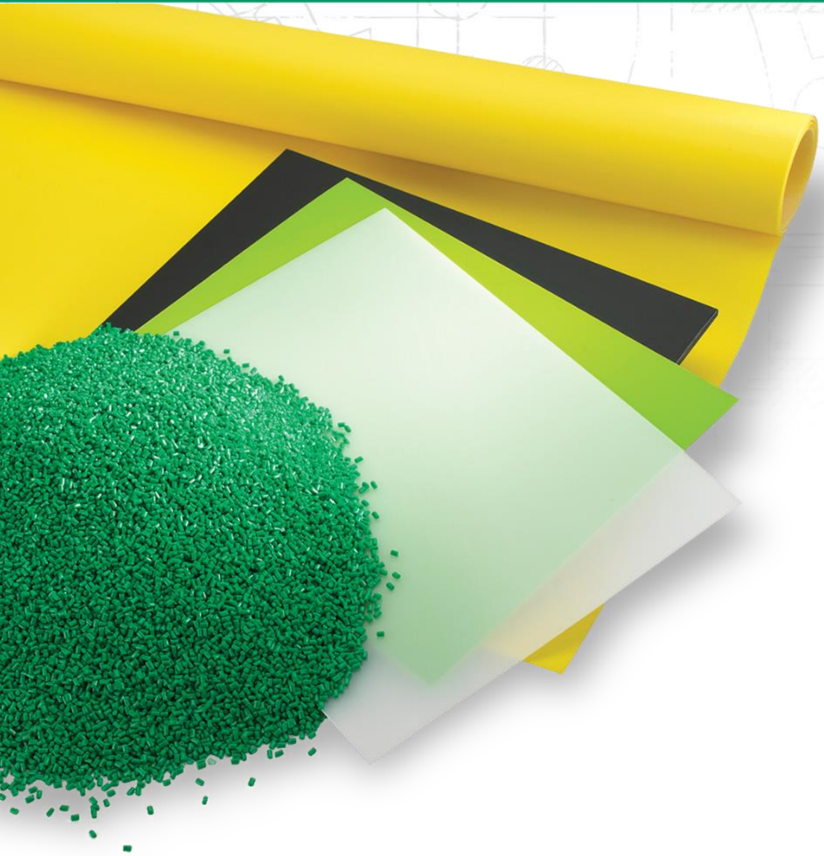
PUTTING IT ALL TOGETHER

Step 1: Use Resin Morphology

Step 2: Use Thermal and Cost Requirements

Step 3: Fine Tuning and Special Features

Test Your Knowledge With Application Examples



Section 3:

APPLICATION CASE STUDIES

CASE STUDY

CD jewel case

- Transparent
- Flat and dimensionally stable
- Low cost

PS

CASE STUDY

Gas tank

- Good chemical resistance
- Good low temperature impact
- Low cost

HDPE

CASE STUDY

Auto tail lamp cover

- Transparent colors
- Dimensionally stable
- Excellent UV resistance
- Low cost

PMMA

CASE STUDY

Plastic tumblers

- Transparent
- Reasonable thermal and chemical resistance (dishwasher cycles)
- Low cost

SAN

CASE STUDY

Sump pump housing

- Chemical resistance
- Reasonable thermal resistance
- Low cost

PP + GF

CASE STUDY

Safety glasses

- Optical transparency
- High impact
- Moderate cost OK

PC

CASE STUDY

Hub odometer lens

- Transparent
- Good chemical resistance
- Moderate-high cost OK

Amorphous Nylon

CASE STUDY

Chemical beakers

- Excellent chemical resistance
- Low cost
- Transparent

?????????

CASE STUDY

Nail gun housing

- Good chemical resistance
- Excellent strength, stiffness, and impact
- Good surface finish when reinforced
- Moderate cost OK

Nylon 6 + GF

CASE STUDY

Automotive intake manifold

- Chemical resistance
- Excellent strength, stiffness, and impact
- Moderate heat resistance
- Moderate cost OK

Nylon 6,6 + GF

CASE STUDY

Oil pan

- Chemical resistance
- Excellent strength, stiffness, and impact
- Moderate heat resistance
- Moderate cost OK
- Extremely tight dimensions and flat

?????????

CASE STUDY

Electrical connectors

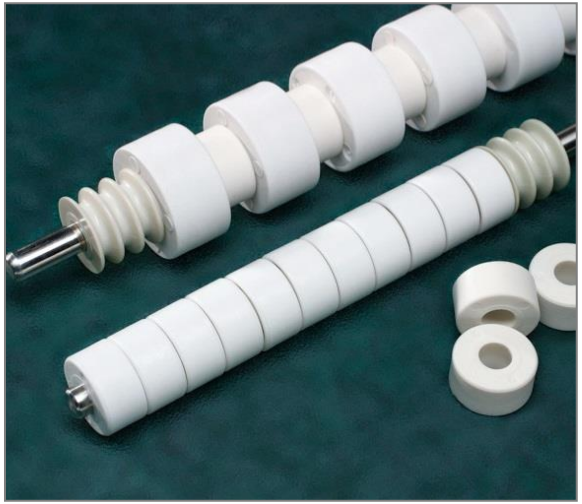
- Good flow in thin walls
- Excellent electrical properties
- Dimensionally stable in humidity
- Moderate cost OK

PBT (PET) + GF + FR

CASE STUDY

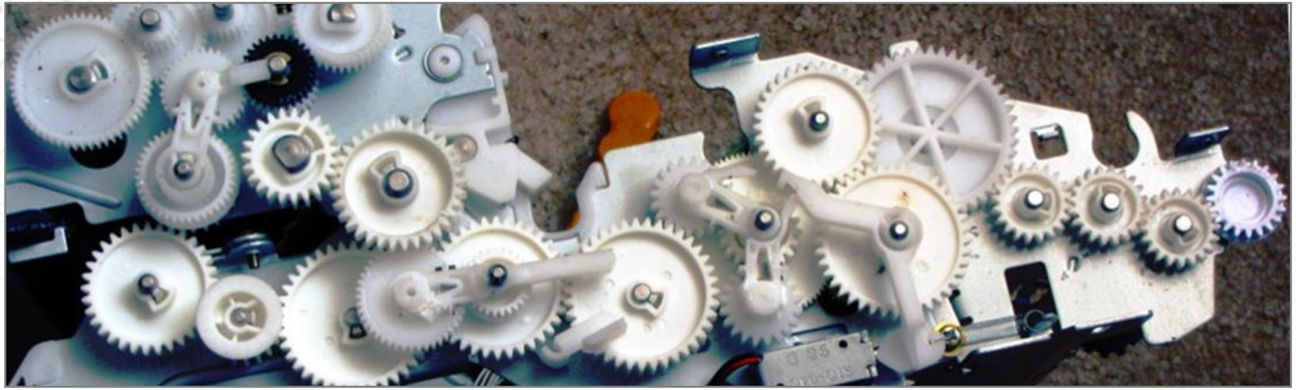
Conveyor rollers

- Good abrasion resistance
- Low wear and friction
- Moderate cost OK



Acetal

CASE STUDY



Printer gears

- Extremely tight dimensions
- Moderate cost OK
- Good abrasion resistance
- Low wear and friction

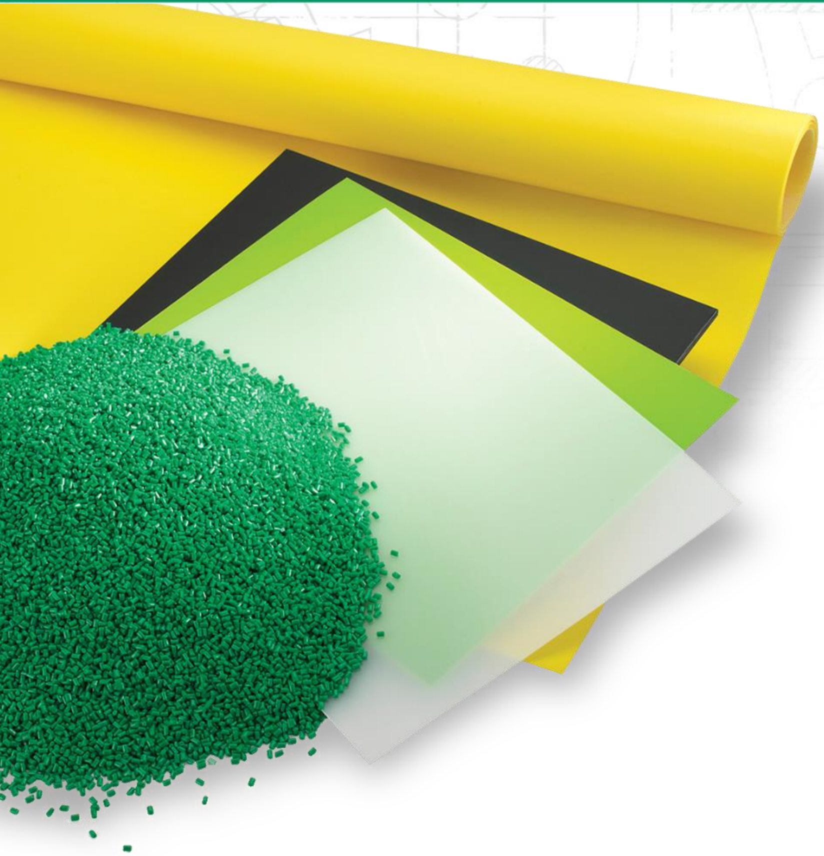
??????????

CASE STUDY

Lawn tractor hood

- Tight dimensions and low warp
- Moderate cost OK
- Chemical resistance
- Good mold flow

?????????

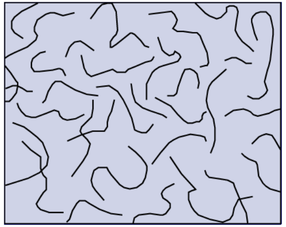


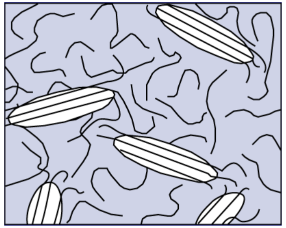
Section 4:

COMPOUNDING TO ENHANCE PERFORMANCE

MORPHOLOGY DEFICIENCIES

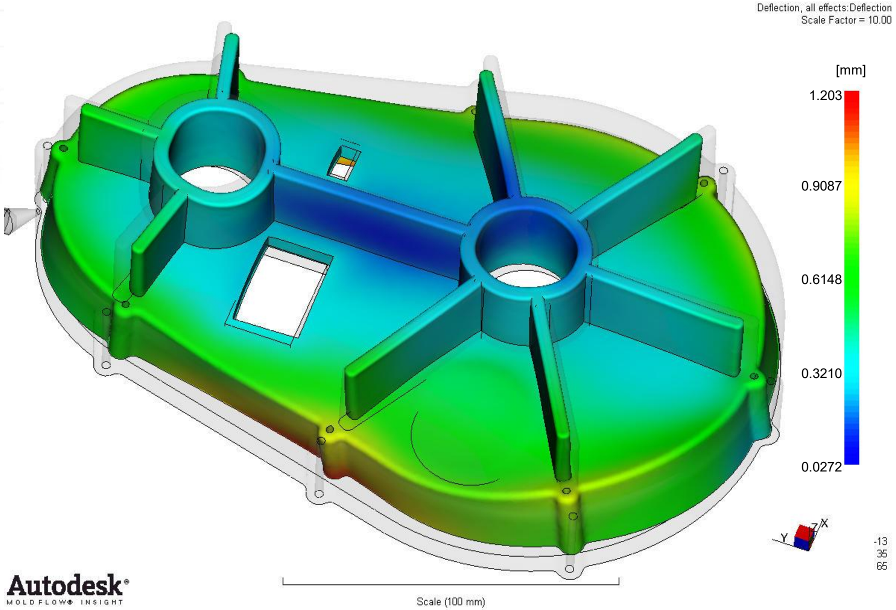
	Amorphous	Semi-Crystalline
Low Shrinkage	O	D
Low Warpage	O	D
Tight Tolerances	O	D
Transparency	O	D
Mold Flow Ease	D	O
Chemical Resistance	D	O
Wear Resistance	D	O





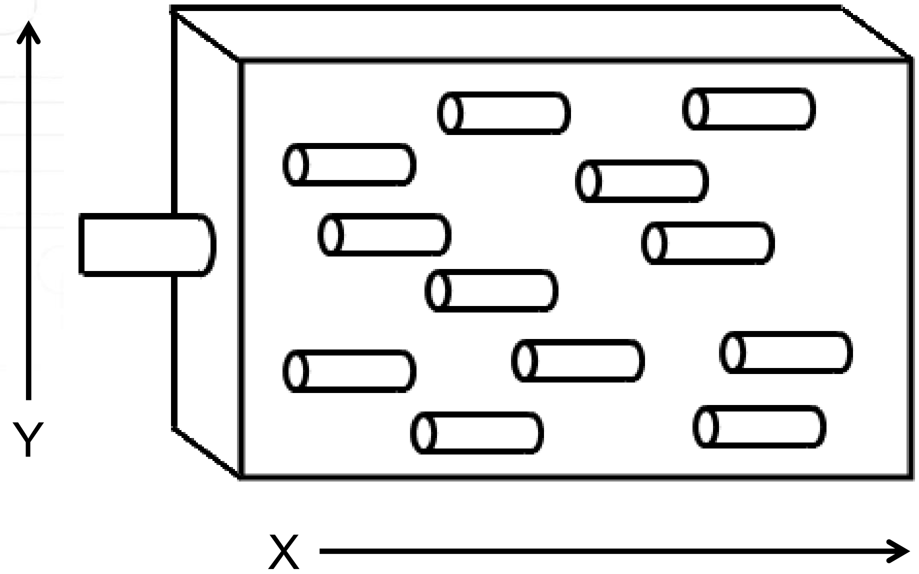
DIMENSIONAL STABILITY

Can we reduce shrink rate and improve dimensional stability of Semi-Crystalline resins?



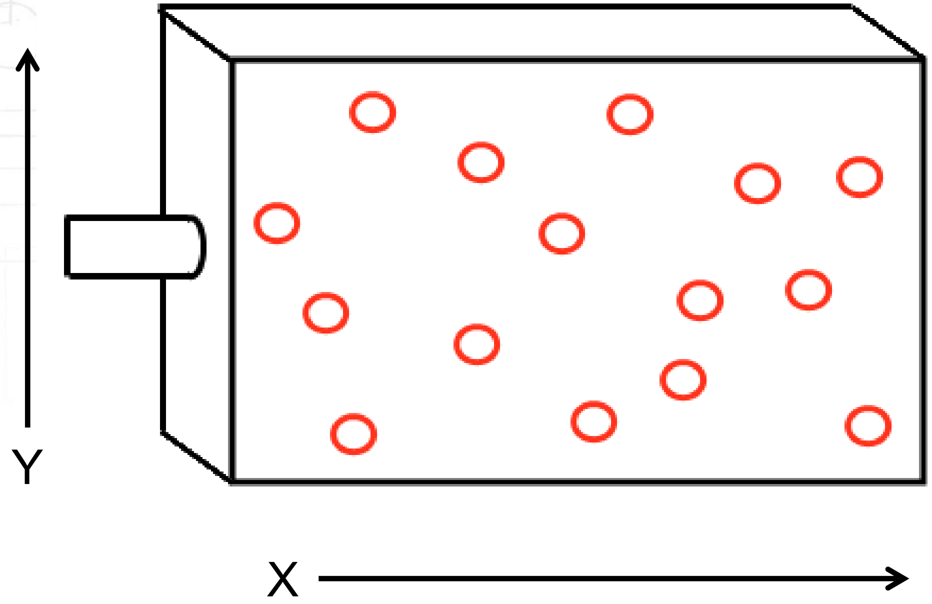
RTP Co. Imagineering Plastics

FIBER REDUCES SHRINK



Shrink Rate X ≠ Shrink Rate Y → Warp

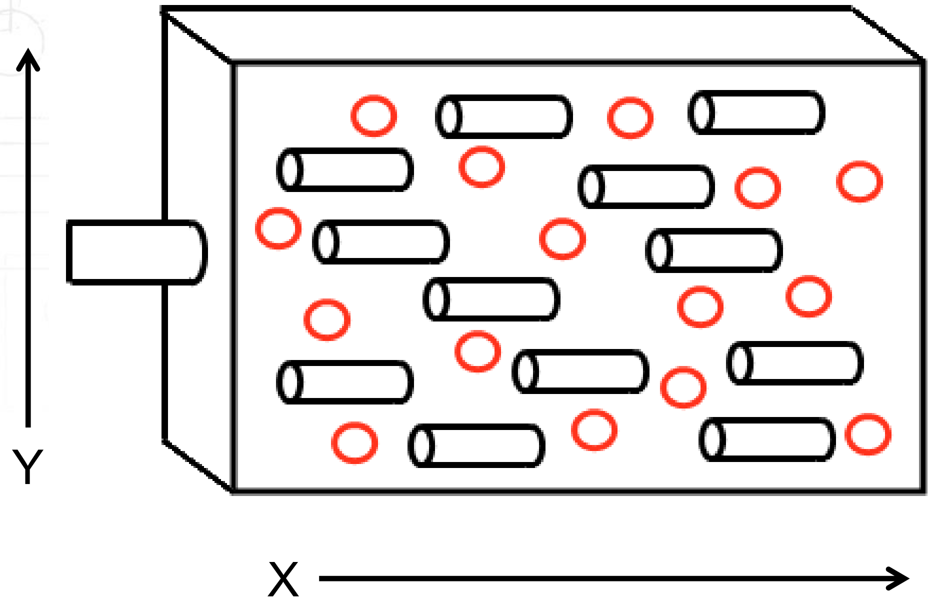
WARP CONTROL



Shrink Rate X = Shrink Rate Y ⟹ Flat Part

But Low Strength!

STRENGTH & WARP CONTROL



Common Loading = 15% Glass Fiber and 25% Mineral or Beads

CASE STUDY

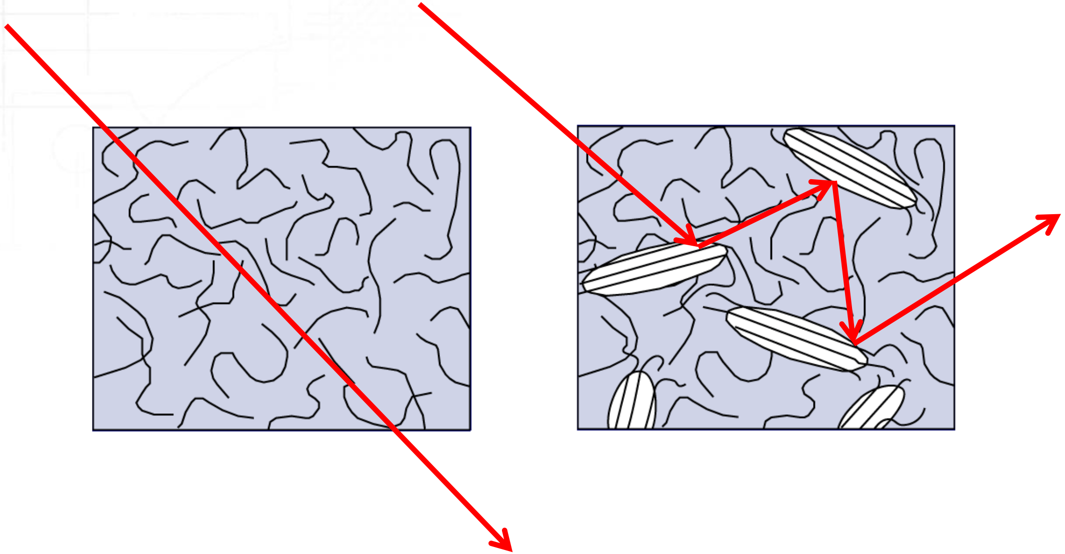
Oil pan

- Chemical resistance
- Excellent strength, stiffness, and impact
- Moderate heat resistance
- Moderate cost OK
- Extremely tight dimensions and flat

Nylon 6,6 + 15% GF + 25% Mineral

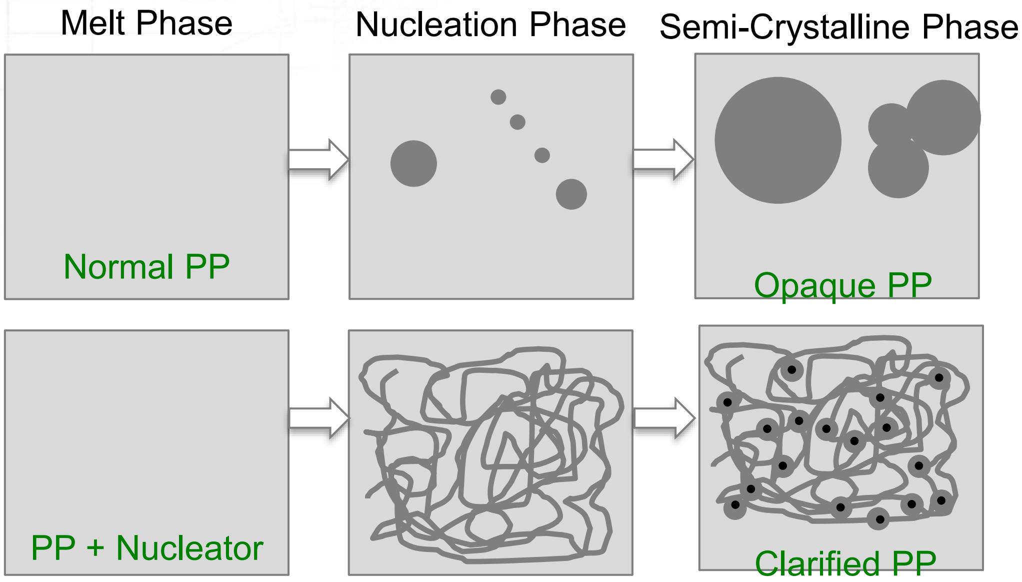
TRANSPARENCY

Can we make a Semi-Crystalline resin transparent?



NUCLEATION/CLARIFICATION

Compounding nucleator into PP or PE controls crystal size to less than wavelength of light = Transparency



CASE STUDY

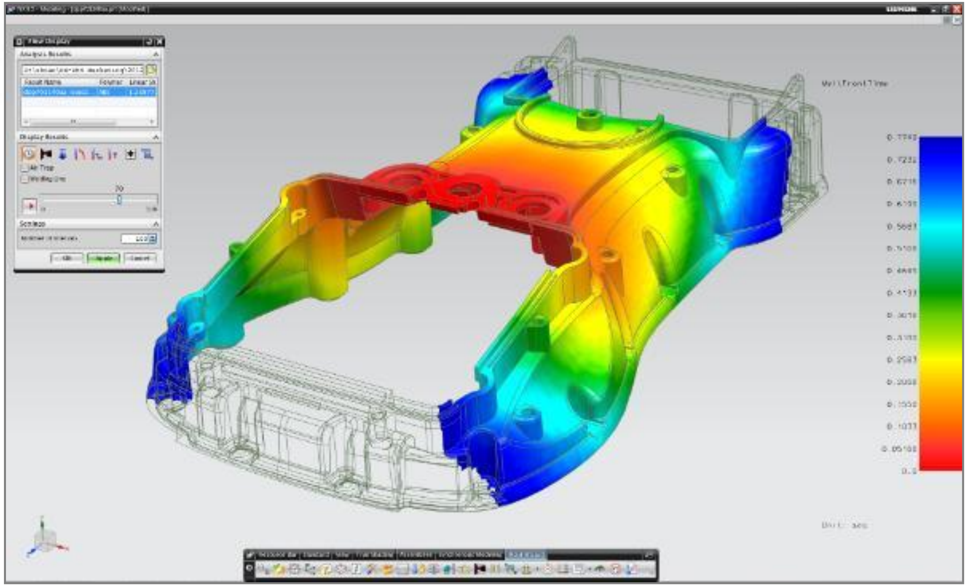
Chemical beakers

- Excellent chemical resistance
- Low cost
- Transparent

PP + Nucleator

CHEMICAL RESISTANCE/MOLD FLOW

Can we improve chemical resistance and mold flow of amorphous resins?



ALLOYING

Alloy PC with ABS
RTP 2500 A Series

	PC	PC/ABS
Tensile Strength, psi	9000	8900
Flexural Mod, E6 psi	0.34	0.40
Izod Impact, ft lb/in	15	13
HDT @ 264 psi,˚F	270	210
Fuel Resistance	Poor	Poor
Melt Flow, gm/10 min	10	15
Clarity	Transparent	Opaque

ALLOYING

Alloy PC With Polyester (PBT or PET)

RTP 2099 X 63578 B

	PC	PC/PBT
Tensile Strength, psi	9000	8700
Flexural Mod, E6 psi	0.34	0.35
Izod Impact, ft lb/in	15	15
HDT @ 264 psi,˚F	270	250
Fuel Resistance	Poor	Fair
Melt Flow, gm/10 min	10	20
Clarity	Transparent	Opaque

CASE STUDY

Lawn tractor hood

- Tight dimensions and low warp
- Moderate cost OK
- Chemical resistance
- Good mold flow

PC/PBT Alloy

WEAR RESISTANCE

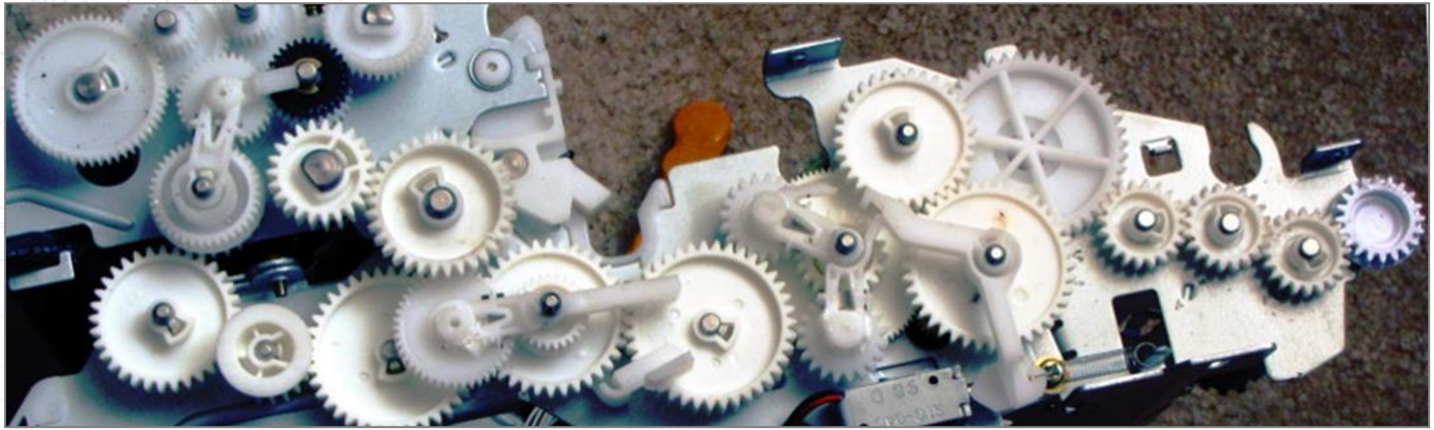
Can we make an amorphous resin wear resistant?

INTERNALLY LUBRICATED

RTP 300 APWA

	PC	RTP 300 APWA	Acetal
Wear Factor	560	130	90
Dynamic Coefficient of Friction	0.60	0.33	0.40

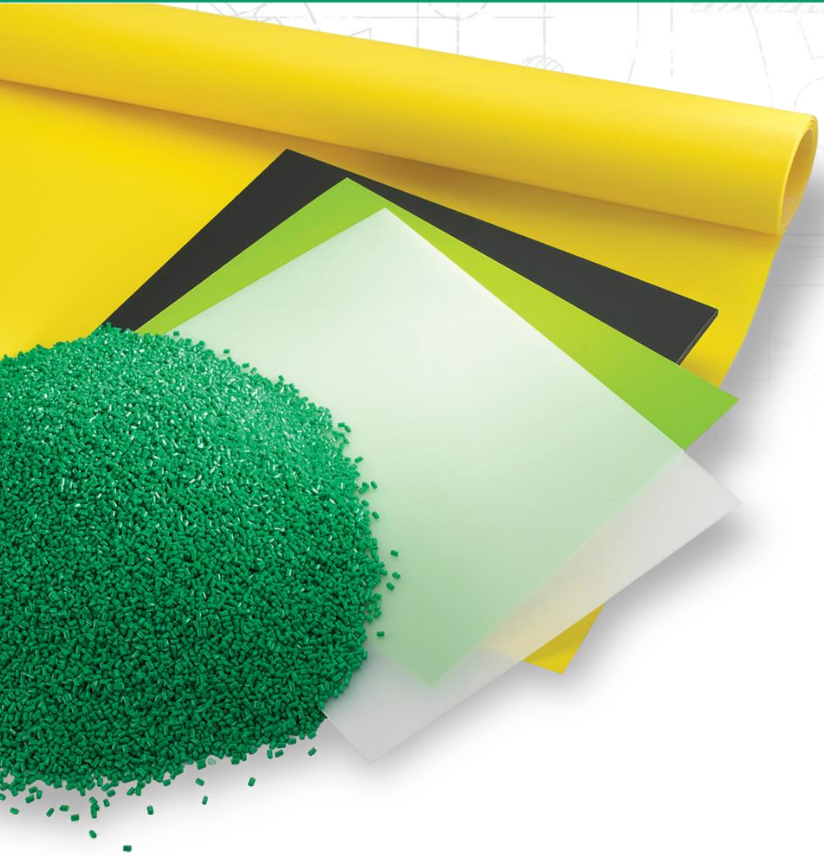
CASE STUDY



Printer gears

- Extremely tight dimensions
- Moderate cost OK
- Good abrasion resistance
- Low wear and friction

Internally Lubricated PC



Section 5:

WHAT’S NEW?

NEW TECHNOLOGIES

NEW TECHNOLOGIES

- Chemical resistant options for medical equipment housings
  - RTP 2000 HC FR A
- IR reflecting colors
  - Allow dark color plastics to remain cool when exposed to sunlight
- Non-PFAS internally lubricated wear resistant materials
  - APWA, ABR, SPR Compounds
- UL2043 plenum space materials
  - Low heat and smoke release for speaker housings, HVAC vents, Lighting, Wireless access points
- Sustainable materials
  - Post-industrial, Post-consumer recycled
  - Bio sourced materials

REVIEW

Intro to compounding

The dilemma

Resin selection procedure

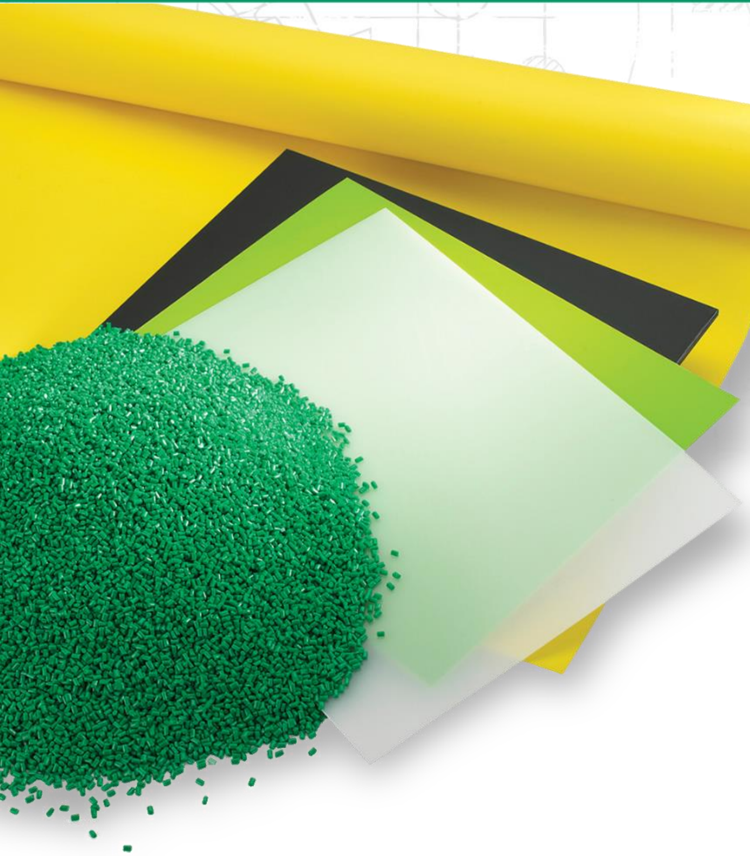
- Resin morphology
- Resin cost and thermal performance
- Unique resin features

Application case studies

Compounding in performance

- Overcoming resin deficiencies

Introduction to new technologies



THANK YOU!

Questions?

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