A Smithers Group Company

Why Plastic Products Fail

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To provide our customers with Research, Consultancy and Information on all aspects of Plastics, Rubber & Composite Technology

- **Smithers Rapra**
  - **Polymer Consultancy**
  - **Material & Product Testing**
  - **Chemical Analysis**
  - **Manufacturing & Processing**
  - **Research Projects**
- ***i*Smithers**
  - **Training Courses**
  - **Polymer Library**
  - **Conferences**
  - **Publications**

UKAS CALIBRATION No. 0306 | UKAS TESTING No. 0067

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Polymer Consultancy 2

- Product design & development
- Process optimisation
- Failure diagnosis
- Regulatory advice & testing:
  - Pharmaceutical & medical devices
  - Food contact testing

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The Consequences of Plastic Product Failure 3

- Smithers Rapra has undertaken over 5000 polymer relate product failure investigations
- We receive > 25 new plastic cases a week from a diverse clientele:

Automotive
Aerospace
Agricultural
Construction
Domestic Appliances
Energy

Defence
Electronics
Medical
Pharmaceutical
Offshore

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Plastic Product Failures on the Rise

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Product failure is rarely reported.

"No one wants their dirty washing aired in public"

- Those responsible are naturally generally reluctant to publicise the fact - loss of confidence / credibility in the marketplace
- Failure investigation is a covert activity – they can't be disclosed due to client confidentiality agreements

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The Consequences of Failure

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Product failure is a costly business!

The consequences of failure include:

- Product liability
  - significant settlements and penalties
- Loss of brand credibility & competitive edge
- Expensive recalls
- Warranty claims
- Re-tooling
- Costs for independent failure investigations to settle legal disputes, insurance claims

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Product Liability – Some Pointers

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A manufacturer may be held liable if the product:

- Is defective and not fit for purpose
- Is manufactured defective and proper testing and inspection was not conducted
- Lacks adequate labelling, instruction & warnings
- Unsafely packaged
- Official records of product sale, distribution & manufacture are not controlled and kept up to date
- Records of customer complaints, failure investigations & liability incidents are not maintained

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Why Plastic Products Fail

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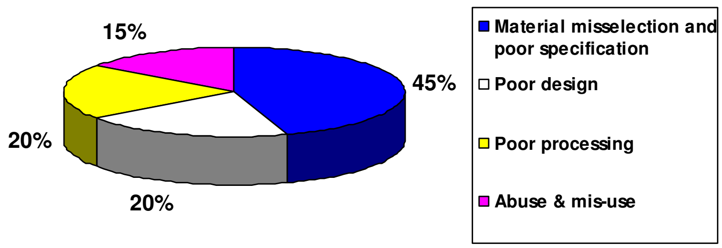
Why such a high volume of plastic failure cases?

At Smithers Rapra we have established that human weakness or error
is the driving factor for product failure not material weakness or process fault

Human Causes of Failure (%)



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Plastics Versus Traditional Engineering Materials

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- A fundamental problem is a lack of understanding between the nature of polymeric materials and traditional engineering materials such as metals.
- With metals, their yield stress is fixed as a function of temperature (which varies very little between -60°C and 250°C)
- With metals designers can generally disregard effect of temperature, environment and long term effect of load
- With metals designers can rely on instantaneous stress / strain properties

None of the above can be applied to Plastics!!!

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Plastics Failure - Overview

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- ❑ Failure modes
- ❑ Visco-elastic behaviour
- ❑ Design data
- ❑ Material selection
- ❑ Component design
- ❑ Process faults

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Failure Modes – Brittle Fracture

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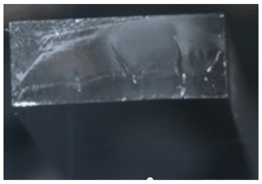
- Sudden catastrophic failure in which rapid crack propagation is observed with negligible plastic deformation.
- Can occur at stresses significantly lower than yield strength, low strains.
- After crack initiation no further energy required to drive propagation
- Fracture surfaces are typically smooth and glassy in appearance
- **All plastics even wholly ductile, tough materials can fail in a brittle manner!!!**



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Failure Modes – Ductile Deformation

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- A slow, non catastrophic failure mode
- Occurs when yield strength is exceeded resulting in gross deformation and gradual tearing of surfaces
- Additional energy must be provided by external loading to propagate crack
- Characteristic features
  - crazing & stress whitening
  - jagged and torn surfaces
  - necking (reduction in cross-sectional area), elongation

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Visco-elastic Behaviour

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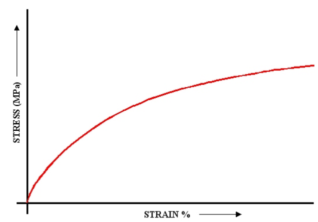
Plastics are visco-elastic and respond to stress as if they were a combination of elastic solids and viscous fluids.

- **solid characteristics** - elasticity, strength and form stability
- **liquid characteristics** – they in effect flow – dependent on time, temperature, loading and rate applied



➡ Exhibit a non linear stress-strain relationship

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Visco-elasticity

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Properties are dependent on:

- ❑ Stress
- ❑ Strain rate
- ❑ Temperature
- ❑ Time
- ❑ Environmental factors
- ❑ Design geometry

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Plastics Design Data

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The designer must consider:

- Tensile creep
- Stress relaxation
- Creep rupture
- Dynamic fatigue
- Notch sensitivity
- Effects of temperature and environment

To ignore this fundamental property will result in under designing and the increase in likelihood of premature failure in use.

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Tensile Creep Effects

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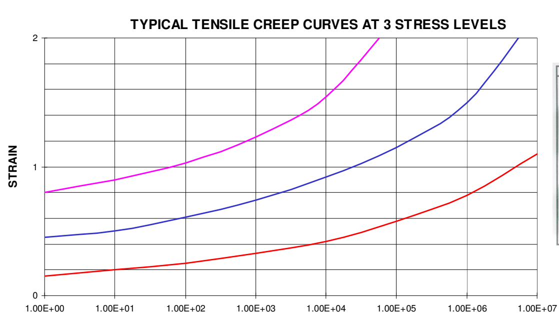
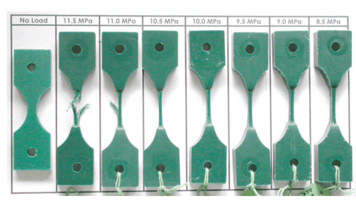
CREEP- The time dependant non-reversible deformation of a material exposed to a constant stress.

ALL (unreinforced) plastics exhibit **significant creep** characteristics.





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Designing for Stiffness

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- The modulus of a thermoplastic reduces significantly with time and temperature
- For design stiffness must be based upon suitable long term modulus values derived under real life conditions
- Structural rigidity is a combination of both material stiffness and component design

Many design errors are made by using the modulus derived from short-term test data given by technical data sheets. This will ensure part is under designed and guarantees failure!!!

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Stress Relaxation

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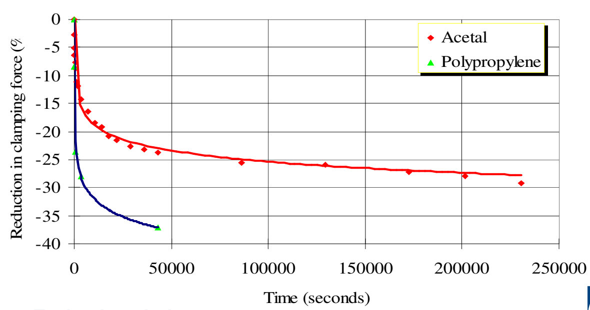
The decrease in stress which occurs with time when a material is held at a constant deformation and is due to the same material processes as creep.

In plastic springs, interference fits, screws, washers and mechanical joints the restoring force will decrease with time.



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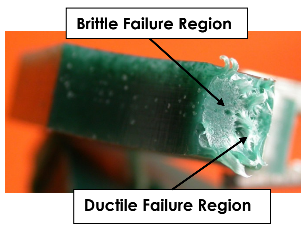
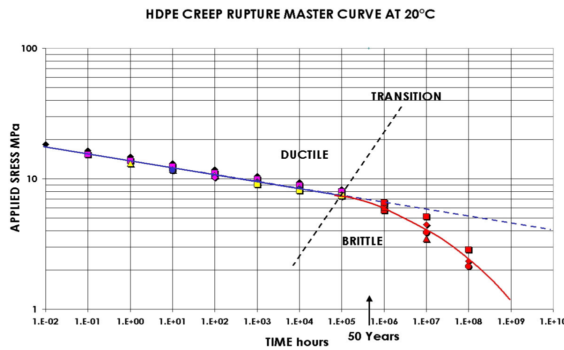
Creep Rupture (Static Fatigue)

Creep rupture is the terminal event of creep and is a measure of the time that a material under a constant applied tensile load takes to fail.
Plastic materials fail, with time, **at stress levels significantly below** the short term tensile strength of the material.

The failure mode will, at some stress level change from ductile to brittle

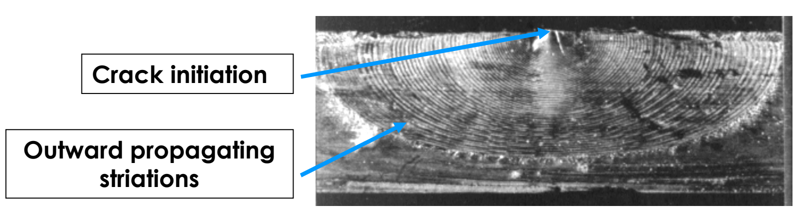




Dynamic Fatigue

- The application of a cyclic short-term stress resulting in small increments of damage resulting in initiation and gradual propagation of a brittle crack which fails at some point in a catastrophic manner

- Fatigue failure is identifiable by striations showing incremental crack growth.

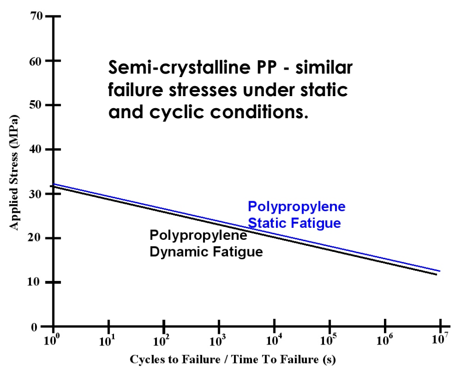


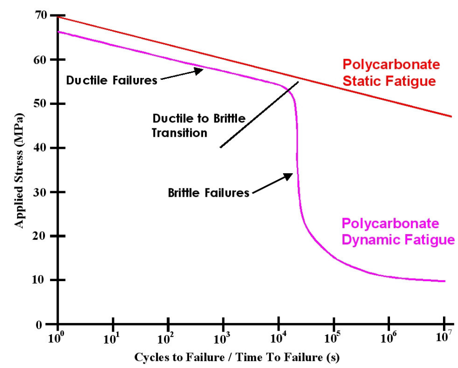
- As with creep rupture the material will fail, with time/cycles, **at stress levels significantly below** the short term tensile strength

Thermoplastic Dynamic Fatigue

Generally amorphous thermoplastics are more sensitive to dynamic fatigue than semi-crystallines

A sharp ductile-brittle transition may occur after a low number of cycles for amorphous thermoplastics





Typical Fatigue Failure Strains (10^6 Cycles)

Polymer		Strain % (10^6 cycles)
Amorphous	PC	0.55
	PES	0.45
	PMMA	0.45
	uPVC	0.3
	ABS	0.4
Semi-crystalline	POM	0.75
	PA66	1.0
	PP	1.0

Design Limits

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Allowable design strains

Polymer	Static	Dynamic
Amorphous	0.5%	0.3%
Semi-crystalline	0.8%	0.6%

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Other Factors– Notch Sensitivity

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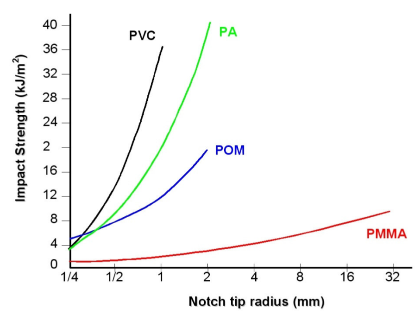
Thermoplastics can be split into two classes, those that exhibit inherent tough ductile behaviour and those that exhibit inherent brittle behaviour

All thermoplastic will however exhibit brittle behaviour if the rate of impact is sufficiently fast or the notch tip radii is sufficiently sharp



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Other Factors– Environmental Stress Cracking (ESC)

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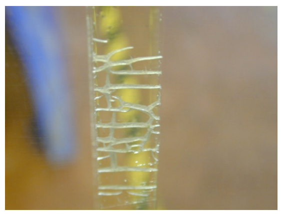
- Crazing and brittle cracking when exposed chemical environment in combination with tensile stress
- It is a failure mechanism, which contributes to many industrial and domestic accidents with substantial costs to industry
- Amorphous thermoplastics are more susceptible to ESC than semi-crystalline

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Other Factors - Chemical & Thermal Attack

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Degradation is due to chain scission & reduction in molecular weight

- Results in Loss of mechanical properties, embrittlement & cracking.

Caused by:

- Short and long effects of temperature exposure
- Chemical environment interaction – including water
- UV radiation (indoor / outdoor)
- Ionising radiation
- Ozone
- Oxidation
- Humidity and moisture
- Pollution – acid rain
- Biological

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Factors Influencing Life

- Plastic materials will, under the action of a tensile stress, eventually fail.

- With plastic materials the time to failure will diminish:
  - as the stress increases
  - as the temperature increases
  - in the presence of specific environments
  - under the action of cyclic loading
  - Presence of stress raisers

Material Selection

Failures arising from incorrect material selection and grade selection are perennial problems in the plastics industry!!!

Why?

Plastic Failure due to Material Mis-Selection

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Material selection is a challenge even for plastics experts due to the vast array of plastics available

- Over 90 generic plastic types to choose from
- 1,000 sub-generic plastic types through modification
- 500 suppliers & 50,000 named grades

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Material Selection – The Designers Nightmare

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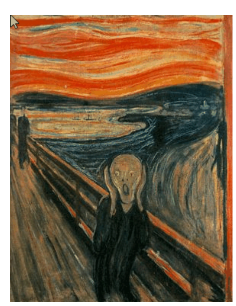
The problems posed by material selection are further compounded by:

- A plethora of technical information available.
- Poor standardisation of test data
- Difficulty in comparing data on an equal basis
- Limited multipoint data
- Often incomplete, inconsistent data
- Distinct lack of long term design data
- Supplier's trade literature which often extols the advantages and masks the disadvantages
- Limited resources for specialist independent advice



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Designing With The Material in Mind

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In order to perform plastic material selection successfully the selector should have a comprehensive understanding of:

- Plastic material characteristics
- Specific material limitations and failure modes
- The need for a judicious approach with careful consideration of application requirements
  - mechanical, thermal, environmental, chemical, electrical and optical
- Production factors such as feasible and efficient method of manufacture in relation part size and geometry need to be assessed
- Economics
  - material cost, cycle times and part price need to be considered

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Pitfall of The Technical Data Sheet

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Short-term plastic data MUST NEVER be used for engineering design or final material selection

- Data is short-term, single point measurements – no consideration of time, temperature, environment or chemical contact
- Derived from ideal test specimens processed and tested under ideal laboratory conditions
- Useful only for comparing the properties of different plastics – a useful screening tool
- Manufacturer quality control guidelines
- Purchase specifications

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Failure due to Material Mis-Use

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Materials substitutions commonly occur when the customer is unable to enforce quality procurement specifications.

Common problems include:

- Processor simply substituting with a cheaper material
- Use of the wrong grade of material (incorrect MFI)
- Use of general purpose PS rather than HIPS
- Homopolymer used instead of copolymer
- Incorrect pigments, fillers, lubricants, stabilisers or plasticisers used

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Plastics Design

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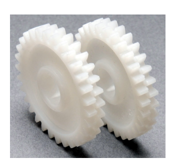
- No absolute rules for plastic design
- The design criteria changes from material to material and application to application
- Always ask your material manufacturer for advice
- There are a few general design principles established which apply to:
  - Wall thickness, radii, fillets, ribs, bosses, holes, draft angles, thread design



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Classic Design Errors Resulting in Failure

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- Direct substitution of traditional engineering material i.e. metal, ceramic, wood with plastic.
- Reduced design safety factors due to cost pressures
- Poor consideration of creep, creep rupture, stress relaxation and fatigue mechanisms.
- No consideration of environmental conditions

Wall Thickness

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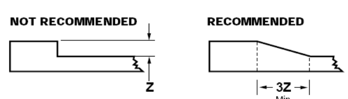
- Uniform wall thickness - is the number one rule for plastics design;
  - it aids material flow
  - It reduces risk of sink marks
  - It reduces moulded in stresses and differential shrinkage
  - for non-uniform walls transition should not exceed 15% nominal wall thickness & corners must always be radiused



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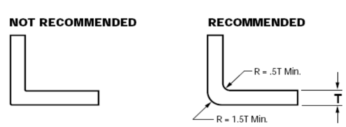
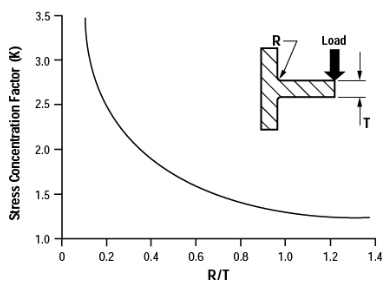


Illustration credit BASF – Design Solutions Guide

Sharp Radii – Stress Concentrations

- Sharp corners must be avoided at all costs - No1 cause of part failure
- They create stress concentrations – Plastics don't like these because they are notch sensitive – toughness & strength are compromised.
- Other stress raisers are holes, notches, abrupt changes in wall thickness



When the corner radius (R) is small compared to the wall thickness (T), a high stress concentration factor results

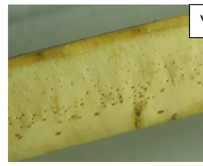
Illustration credit BASF – Design Solutions Guide / Peterson, R.E., Stress Concentrations

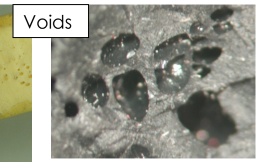
Plastic Failure Due to Poor Processing

At Smithers Rapra we find that even the best plastic designs with good material selection can fail due to:

- A disregard for sound processing procedures and guidelines provided by material manufacturers
- The driving force is typically economic - the need to achieve reduced cycle times, higher production yield or aesthetically pleasing parts

Common Process Induced Plastic Failures

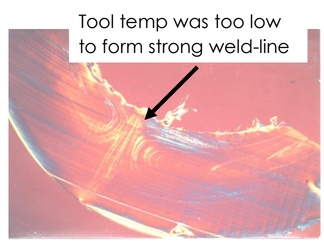




- Poor material drying.
  - volatiles resulting in voids
    - structural weakness
    - stress concentration
  - hygroscopic plastics are prone to hydrolysis (degradation) during processing resulting in embrittlement
    - PC, PET, PBT - modest absorption high degradation rate
    - PA - High absorption lower degradation rate
- Over heated material
  - plastics are heat sensitive and will degrade resulting in embrittlement
    - high temperatures for short periods
    - modest temperatures for long periods
    - high shear

Common Process Induced Plastic Failures

- Improper use of additive / regrind
  - loss of original properties, reduced performance
    - regrind material degraded
    - stabiliser additives depleted
- Poor weld lines / spider lines
  - planes of weakness
  - notch effects – stress concentrations
- Residual stress & molecular orientation
  - will compromise structural integrity under load
  - increased susceptibility to ESC
    - differences in wall thickness
    - short cycle times - frozen in stress
    - non uniform tool temps
    - metal cores/inserts



Common Process Induced Plastic Failures

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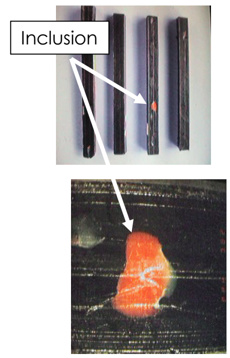
- Material contamination / inclusions
  - structural weakness / stress concentration.
- Poor material mixing
  - planes of weakness, stress concentrations
- Development of low or excessive crystalinity
  - high crystalinity – embrittlement
  - low crystalinity – loss of properties
- Under or over packing
  - optimum physical properties not achieved
    - weak weldlines
    - voiding
    - high residual / orientation stress
    - poor microstructure



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Summary

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For successful plastic product design
NEVER use short term data & always consider:

- TIME – TEMPERATURE – RATE dependency
- Long term behaviour CREEP & FATIGUE effects
- Notch sensitivity
- ESC
- Processing effects
- Design geometry
- Remember that compromise & trade-offs can lead to failure

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