If you don't know the fords, don't step in the water!
Contents

- **Polymers**

- *Typical failure mechanisms of plastics*: failure might occur.

- *Failure causes of plastic products*: failure has occurred.
Polymerisation of ethylene $\text{C}_2\text{H}_4 \rightarrow \text{PE}$
Polyethylyene $\text{C}_2\text{H}_4$

unbranched

branched
Verdeling Molecuulmassa

- Molecular mass
- Chain length

Diagram showing the distribution of molecular masses with a peak at $M_i$.
Chain length of PE ($C_nH_{2n+2}$)

- **paraffin** (500 g/mol)
- **glue container** ($10^5$ g/mol)
- **UHMW-PE** ($5 \times 10^6$ g/mol)

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Amorphous and semi-crystalline

A - amorphous structure  
B - crystalline region  
C - semi-crystalline structure  

low binding energy  
high binding energy  
tie-molecule  

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Bending strength and impact strength as a function of $M_n$
Viscosity as a function of molecular mass

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Spoormaker Consultancy in Reliability & Liability of Plastic Products

Injection moulding of thermoplastics

All you need is speed !!!

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## Failure mechanisms and causes

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## Fatigue

### Failure Mechanisms
- UV-degradation
- creep & stress relaxation
- environmental stress cracking
- dimensional stability
- static fatigue
- dynamic fatigue
- wear

### Failure Causes
- faulty ribbing
- difference in stiffnesses
- high stiffness of mating parts
- grade and polymer selection
- stress concentrations
Disentanglement in polymers can occur, resulting in stable crack extension. This is also referred to as static fatigue. Dynamic fatigue is a similar mechanism.
Dynamic crack growth Paris law

\[ \frac{da}{dN} = C_d \cdot (\Delta K_I)^m \]

- \( \frac{da}{dN} \): Crack growth per cycle
- \( C_d \): Constant for dynamic loads
- \( \Delta K_I \): Stress intensity difference
- \( m \): Exponent

\[ (\Delta \sigma \cdot Y(a/W) \sqrt{\pi \cdot a}) \]
Crack extension

\[ \frac{da}{dN} = C_d \cdot (\Delta K_I)^m \]

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Static fatigue

\[
\frac{da}{dt} = C_s \cdot K_I^n
\]

Crack growth rate

\[
\frac{da}{dt} \quad C_s 
\]
Constant

\[
K_I 
\]
Stress intensity

\[
n
\]
Exponent

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Static fatigue crack growth

- Initial crack initiation
- Stable crack extension
- Unstable crack extension

Crack growth rate vs. $K_1$

- $da/dt$ vs. $K_1$
- $K_{lc}$
# Polycarbonate spring

## Failure Mechanisms
- UV-degradation
- creep & stress relaxation
- environmental stress cracking
- dimensional stability
- static fatigue
- dynamic fatigue
- wear

## Failure Causes
- faulty ribbing
- difference in stiffnesses
- high stiffness of mating parts
- grade and polymer selection
- stress concentrations
PC-spring in service position
Photo of PC spring in service position
Spring in unlocked position
Photo of Spring in unlocked position
Polycarbonate (PC) has relatively *smooth molecular chains* and has a low resistance to stable crack extension. It has, however, a large resistance to crack initiation.
Impact & notch sensitivity

Graph showing the impact strength in kJ/m² as a function of notch tip radius in mm for ABS and PC materials. The ISO-standard is also indicated.

Diagram illustrating the setup for a notched impact test with a pointer, hammer, scale, and specimen.
Failed springs

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SEM of fracture surface (static fatigue)
SEM of fracture surface (dynamic fatigue)
Melt Flow Rate (MFR)

MFR - the mass of polymer, in grams, flowing in 10 minutes through a capillary of a specific diameter and length by a pressure applied via prescribed weights for prescribed temperatures.
Relationship between the Molecular Weight and the MFR for PC (Calibre 300 of DOW Plastics)
Relation MFR-Impact strength

- 0.25 mm notch radius
- 0.20 mm notch radius
- 0.13 mm notch radius

Notched Izod Impact, kJ/m²

Melt Flow Rate, g/10 min (300°C/1.2 kg)
## Kid-Sit

### Failure Mechanisms
- UV-degradation
- creep & stress relaxation
- environmental stress cracking
- dimensional stability
- static fatigue
- dynamic fatigue
- wear

### Failure Causes
- faulty ribbing
- difference in stiffnesses
- high stiffness of mating parts
- grade and polymer selection
- stress concentrations

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Kid-Sit
Kid-Sit stiffness differences

Extreme high stiffness differences between swivel plate (steel) and the board adjacent to the swivel plate (polymer)
Kid-Sit - cracking

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Fatigue

S-N curves for some polymers

Semi-crystalline (final material selection PA6 with 30 % glass fibres)

Amorphous (initial material selection)

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S-N curve of PA66-30GF (flow direction)
Extreme high stiffness differences between swivel wheel plate (steel) and the board adjacent to the swivel plate (polymer)

Bending stiffness $D_{sw} = E_s \cdot I_{na} = 82 \text{ Nm}^2$

$D_b = E_p \cdot I_b = 2.9 \text{ Nm}^2$

$D_{sw} \backslash D_b = 31$
Impact factor $\psi$

$$\psi = \frac{F_{\text{impact}}}{F_{\text{static}}} = 1 + \sqrt{\frac{2h}{mg}} k_{\text{tot}} + 1$$
Impact factor $\psi$

$$
\psi \ = \ \frac{F_{impact}}{F_{static}} \ = \ 1 \ + \ \sqrt{\frac{2h}{mg}} \ k_{tot} + 1
$$

$h = 0.1 \ m$
$m = 18 \ kg$
$g = 9.8 \ m/s^2$
$k_{tot} = 22000 \ N/m^2$

$$
\psi \ = \ 1 + \sqrt{\frac{2 \cdot 0.1}{18 \cdot 9.8}} \ 22000 + 1 \ = \ 6.1
$$

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Kid-Sit FEM calculation I

Very high secondary stresses in the region near the stiffness difference

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FEM calculation (filliting)

Still very high secondary stresses in the region near the stiffness difference. **Filletting does not help**

ECEFA -IV
**UV-degradation**

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Weathering
Weathering

1. Definition
2. Sunlight and spectral sensitivity
3. Effect of UV on polymers
4. Attack of bonds
5. Change in mechanical properties
Definition of weathering

*Weathering* is the adverse response of a *material or product* to climate, often causing unwanted and premature product failures.

**Primary Factors of Weathering:**

- solar radiation (light energy)
- temperature
- water (moisture/dew)
Weathering

1. Definition
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3. Effect of UV on polymers
4. Attack of bonds
5. Change in mechanical properties
Solar radiation spectrum
Weathering

1. Definition
2. Sunlight and spectral sensitivity
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5. Change in mechanical properties
UV-induced reactions

Polymer → \( R^\cdot \)

\( R^\cdot + O_2 \rightarrow RO_2^\cdot \)

\( RO_2^\cdot + R'^\cdot H \rightarrow ROOH + R'^\cdot \)

\( R'^\cdot + O_2 \rightarrow R'O_2^\cdot \)

- Loss of H-atom
- Reaction with \( O_2 \)
- Reaction with a molecule
- Reaction with \( O_2 \)
Hydrogen peroxide & hydroperoxide

\[ \text{ROOH} \rightarrow \text{RO} \cdot + \cdot \text{OH} \]
Degradation reactions

- $O_2$
- $R^*$
- ROOH
- RH
- ROO
- ROOH
- ROH + HOH
- $R^*$
- $2R^*$
- ROOH
- ROO
- ROH + HOH
- $2R^*$
- ROO
- ROH + HOH
- $2RH$
- $RO^* + \cdot OH$
Weathering

1. Definition
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Attack on bonds
Pattack on bonds
Transferring of energy
Weathering

1. Definition
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Scission and cross-linking

ECEFA -IV
Chain scission and cross linking
UV - embrittlement

![Graph showing force vs. displacement with UV exposure time points](image)
Polypropene (PP)

![Graph showing degradation of specimens](image)

- ○ degraded specimens
- ● notched specimens

**ECEFA -IV**
Ultra violet stabilisation (Tinuvin)

Dart drop impact strength [J/mm]

- No Light stabilizer
- TINUVIN® 360
- TINUVIN® 1577

Dart Drop: m=28.75kg, h=1.0 m (5 Sample)

PET-G after 0 months Florida
PET-G after 3 months Florida

Time Florida [months]
# Keysaver

## Failure Mechanisms
- UV-degradation
- creep & stress relaxation
- environmental stress cracking
- dimensional stability
- static fatigue

## Failure Causes
- faulty ribbing
- difference in stiffnesses
- high stiffness of mating parts
- grade and polymer selection

## Failure Mechanisms
- dynamic fatigue
- wear

## Failure Causes
- stress concentrations
- improper mould design
Construction of KEYSAVER

Detail of click boss

bobber with spool

Keysaver in transparent ABS

Parts of Keysaver with keys to be saved

ROSMOULD 2006
Floating device

6 mm
Functioning and non-functioning KEYSAVERS
Critical points

**Dimensions**
- Diameter of snap-fit disk
- Height of bosses

**Material selection**
- Snap-fit disk (PA6)
- Inner housing ABS

**Processing and gating**
Lay-out of KEYSAVER
Critical dimensions

$D_d$ – diameter of disk
$D_b$ – diameter of boss circle

Force to unclick is depends on:

$$D_d - D_b$$
Macro photo of boss
Equilibrium of water absorption in air

3 % water uptake!!
Deformation of inner house (ABS) – (bw)
Deformation of ABS test bars
**Critical dimensions**

- **$D_d$** – diameter of **disk**
- **$D_b$** – diameter of **boss circle**

Force to unclick is depends on:

$$D_d - D_b$$
Effect of stiffness on scatter

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Stiffness
# Failure mechanisms and causes

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<tr>
<td>• dynamic fatigue (temperature)</td>
<td>• improper mould design</td>
</tr>
<tr>
<td>• wear (heat, hardness)</td>
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Adhesive wear
Abrasive wear

A hard deeltje

B ruwheidstop
Pitting as a result of fatigue
Wear
Wear (NX-UHMWPE)
Conclusions

1. Basic understanding of **structure related properties**.
2. Typical **failure mechanisms and causes**.
3. Material and grade selection.
4. Do not rely on injection moulders
5. More education in designing in plastics is necessary
Literature list

Polymers

- McCrum, N.G. et al., Principles of Polymer Engineering, Oxford University Press.
- Peter C. Powell & A.J. Ingen Housz Engineering with Polymers

Failure of Plastics