Micro-Mechanism of Laminated Packaging Material during Fracture

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Contents

• Background
• Fracture behaviour of Al-foil (6-7 μm) as single layer
• Al-foil laminate with polymer (LDPE 25 μm)
• Compare with a Special PP (about 20 μm) laminated with LDPE
• Conclusion
Material of Aseptic Packaging

www.tetrapak.com
Crack Propagation in Al-foil

Load vs Crack Length

SEM Photos

(a)

(b)
Image and Profile of Al-foil

Thickness 6.42μm

Malmö Univ., 2002
Fracture Mechanics Model for Al-foil

Strip Yield model with a geometry correction $f$:

LEFM model:

Experiment

$Kc = \sigma_b \cdot f \cdot \sqrt{\frac{8.a}{\pi} \cdot \ln \left[ \sec \left( \frac{\pi \cdot \sigma_c}{2 \cdot \sigma_b} \right) \right]}$

$f(a/w, b/w)$ is Geometry related functions
A is crack length and $\sigma_b$, $\sigma_c$ is measured stress.
Possible Paths for Crack Growth

1. Crack propagated in Al-foil.
2. Crack deflected into adhesive.
3. Several cracks in Al-foil.
4. Crack penetrated into inside LDPE.
Laminate Process and Specimen
Al/EAA (with different melt temperature)

Influence of melt temperature on the laminate

[Graph showing stress-strain curves at different melt temperatures: 220°C, 250°C, 270°C, 290°C, 310°C. Each curve represents a different temperature, with stress on the y-axis and strain on the x-axis.]
Illustration

[Image of a diagram showing a metal film and polymer substrate with annotations for film rupture and interface debond.]

[Suo 1989]
Load versus Extension

Al-foil

load (N)

extension (mm)

2a = 5mm
Load versus Extension

- Al-foil
- LDPE
Load versus Extension

![Graph showing load versus extension for Al-foil and Al // LDPE compared to LDPE.](image-url)
Load versus Extension

Laminate Al/LDPE

Al-foil

Al // LDPE

LDPE

extension (mm)

load (N)
Load versus Extension

Laminate Al/LDPE

Al-foil

Al // LDPE

\[ F = F + F \]
Al-Foil

LDPE

LDPE/Al-Foil/LDPE, delaminate in both side

LDPE/Al-Foil/LDPE, delaminate only one side
Slip-lines for different adhesives (illustration of FEM results)

[Ståhle etc. 2007]

**No adhesion**

**low adhesion**

**high adhesion**

Draw by X. Chen
**Special PP**

- LDPE/Special PP/LDPE, almost no delamination

**LDPE**

- LDPE/Special PP/LDPE, delamination at one side
Comparison of test cases [Andreasson etc. 2012]

Mean load vs displacement (LDPE/BoPP/LDPE, 5mm Center Crack, MD)

- LDPE/BoPP/LDPE laminated (full adhesion)
- LDPE/BoPP/LDPE no adhesion
- BoPP
- LDPE

// - material in parallel no adhesion
+ - material in parallel with adhesion

2a = 5mm
Conclusions

• A modified strip yield model with a geometry correction is shown to provide a suitable model for Al-foil (6-9 µm).
• This model leads to the conclusion that the crack tip is preceded by a substantial plastic zone as compared with the crack length which is also observed.
• The fracture toughness of the Al-foil is much lower than the value given in handbooks.
• No fracture surface can be observed of this Al-foil under the microscope both as single layer or coated with LDPE.
• Delamination between the layers influence significantly the peak load and fracture toughness with or without slip line.
Thank You for Your Attention!
Al/EAA/LDPE
Plastic zone at crack tip

Figure 5.9. Al-foil from Al/Ldpe (Sep) tested specimen. 
P.C.T-Pre-Crack Tip, C-Centre, C.T-Crack Tip.

Figure 5.10. Plastic Zone in Al-foil.

Figure 5.12. Al/Ldpe specimen. 
P.C.T-Pre Crack Tip, C-Centre, C.T-Crack Tip.

Figure 5.13. Plastic Zone in Al/Ldpe (Lam).

Figure 5.15. Plastic Zone in Al/Adh/Ldpe.

Figure 5.14. Al/Adh/Ldpe specimen. 
P.C.T-Pre-Crack Tip, C-Centre, C.T-Crack Tip.
Laminate with a Crack

\[ u, F \]