

Uni-axial stretching of baled silage wrap films: gas permeation properties

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Introduction

The most common methods of manufacture of silage stretch film are blown and cast extrusion, using low density polyethylene (LDPE) and linear low density polyethylene (LLDPE). Film is pre-stretched during application to ensure a tight film seal is maintained. Generally films are stretched to 1.7 times their original length (Lingvall, 1995). This experiment investigated the effects of uni-axial stretching on the gas permeation properties of films used in baled silage wrapping.

Materials and Methods

Three films were manufactured from LDPE-LLDPE blends (70/30: w/w), using LLDPEs of different densities and melt flow indices (MFIs). These are denoted films A, B and C. The films were manufactured using a cast film extrusion system.

Films were stretched to 1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.4, 2.7 and 3.0 times original length using a specially designed clamping system on an Instron 4411 Universal tensile tester. This also measured the forces generated while stretching.

A manometric gas permeability measuring apparatus was used to determine the permeation coefficient (PC) of film samples. A lower permeation coefficient indicates less gas transmission per unit thickness of film. The apparatus was designed for direct measurement of the gas transmission rate (GTR) through plastic films in accordance with B.S.2782, method 821A, ASTM D. 1434 and similar methods. The test gas was CO₂ (99.8% purity). Five samples were tested for each film at each stretch level.

The crystallinity of the various films was determined using a Perkin Elmer DSC-6, and the samples were heated from 30 to 140°C at a rate of 10 deg C/min. The latent heat (ΔH J/g) was calculated for each sample,

which is a measure of crystallinity. Three samples were tested for each film.

Infra red spectra of the films were obtained using a Perkin-Elmer FTIR spectrometer (spectrum 1000) fitted with a 0.12 μ m zinc selenide grid polariser. The instrument operated with a resolution of 1cm⁻¹ and 40 scans were obtained for each sample. The IR absorbance scans were analysed between 700cm⁻¹ and 750cm⁻¹, for changes in the intensity associated with the *a* and *b*-axes (730cm⁻¹ and 720cm⁻¹) in both the machine (MD) and transverse (TD) direction, which give an indication of the molecular orientation of the films.

Data were subjected to two-way analysis of variance appropriate for a factorial (film and stretch) arrangement of treatments.

Results and Discussion

The gas permeability of films have been reported to be dependant on the film crystallinity and molecular orientation (Laffin, 2004). Crystallinity of polyethylene films is dependant on the density and molecular orientation will be affected by the amount of film stretch. It was shown that the CO₂ permeation coefficient of all films decreased (P<0.001) when stretched, with the biggest reduction exhibited by the film of lowest density (Table 1). The crystallinity of all films increased (P<0.001) with increasing stretch.

All stretched films exhibited an increase in orientation in the MD as indicated by FTIR analysis (*b/a* ratio) in Table 1, and the results also show a change in crystalline structure at around 1.8 to 2.0 times stretch.

Conclusions

The reduction in permeation coefficient recorded indicates the scope for working with more layers of highly stretched films. This may give improved barrier properties with less film applied. However the DSC and FTIR analysis results indicate a change in crystal structure that would result in disimproved mechanical properties.

References

- Lingvall, P (1995), The Bale wrapping Handbook, The Swedish University of Agricultural Sciences.
Laffin, C., Mc Nally, G.M., Forristal, P. D., O’Kiely, P., and Small, C. M, (2004) Antec, 230 – 234.

Table 1. Effect of uni-axial stretching on the permeation coefficient, crystallinity and orientation of films

| Polymer | | | Stretch | | | | | | | | | |
|---------|------------------------------|---------------|---------------------|------|------|------|------|------|------|------|------|------|
| Film | Density (g/cm ³) | MFI (g/10min) | 1.0 | 1.2 | 1.4 | 1.6 | 1.8 | 2.0 | 2.4 | 2.7 | 3.0 | |
| A | 0.918 | 4.5 | PC* | 37.8 | 31.6 | 26.2 | 22.8 | 19.1 | 20.4 | 19.6 | 16.6 | 10.9 |
| | | | Force (mN) | 0.0 | 32.8 | 36.7 | 38.7 | 39.4 | 38.6 | 38.4 | 38.8 | 38.9 |
| | | | ΔH | 64.3 | 70.9 | 67.8 | 61.0 | 72.0 | 64.0 | 67.0 | 78.0 | 85.0 |
| | | | <i>b/a</i> ratio MD | 1.2 | 1.9 | 2.3 | 2.7 | 2.6 | 2.4 | 2.3 | 2.3 | 2.3 |
| | | | <i>b/a</i> ratio TD | 1.3 | 1.4 | 0.0 | 1.6 | 1.7 | 1.7 | 1.8 | 2.2 | 2.0 |
| B | 0.903 | 1.5 | PC* | 63.8 | 52.1 | 41.4 | 33.7 | 30.1 | 32.2 | 22.3 | 24.6 | 25.1 |
| | | | Force (mN) | 0.0 | 32.0 | 22.4 | 24.6 | 25.9 | 26.3 | 26.5 | 27.0 | 27.7 |
| | | | ΔH | 16.3 | 39.8 | 33.6 | 37.1 | 42.8 | 36.1 | 39.6 | 49.7 | 51.1 |
| | | | <i>b/a</i> ratio MD | 1.2 | 1.6 | 1.8 | 2.1 | 2.5 | 2.8 | 2.6 | 2.7 | 2.7 |
| | | | <i>b/a</i> ratio TD | 1.3 | 1.3 | 1.2 | 1.2 | 1.3 | 1.7 | 1.6 | 1.8 | 2.0 |
| C | 0.917 | 4.0 | PC* | 34.6 | 25.3 | 25.9 | 24.0 | 22.1 | 17.9 | 22.2 | 13.0 | |
| | | | Force (mN) | 0.0 | 35.0 | 33.3 | 33.7 | 33.6 | 33.2 | 32.6 | 32.8 | 33.3 |
| | | | ΔH | 51.0 | 61.8 | 56.4 | 56.1 | 59.6 | 59.9 | 67.2 | 67.0 | 60.2 |
| | | | <i>b/a</i> ratio MD | 1.3 | 1.7 | 2.3 | 2.7 | 2.8 | 2.5 | 2.9 | 2.9 | 2.7 |
| | | | <i>b/a</i> ratio TD | 1.4 | 1.3 | 1.2 | 1.4 | 1.4 | 1.5 | 1.7 | 1.8 | 1.8 |

*PC = CO₂ permeation coefficient (cm³(STP)cm⁻¹cm²cm(10⁶)). PC SEM = 0.76, ΔH SEM = 0.75. Stretch (S), Polymer (P) and SxP were each significant at P<0.001 for PC and ΔH .