EFFECT OF PROCESSING CONDITIONS ON MECHANICAL PROPERTIES

MOLECULAR ORIENTATION

There is little doubt that molecular orientation is a major factor in controlling the mechanical properties of polyethylene film. Orientation is imposed by stresses during the blown film fabrication process. There are three main sources of stress:

- Shear stress causing flow of the melt through the die – the resulting orientation is in the longitudinal or machine direction
- Stress developed during the drawing of the melt via the nip rolls, causing longitudinal or machine direction orientation
- Circumferential stress arising from the blowing process by which the film bubble diameter is increased – this imposes orientation in the transverse direction

The polyethylene molecules on being extruded through the die gap are aligned in the direction of extrusion. Because of the narrower die gaps for Alkathene LDPE, this alignment will generally be greater than with LLDPE polymers like Alkatuff.

The melt exiting the die can be typically drawn down between 5:1 and 20:1 in the machine (extrusion) direction for LDPEs, and between 10:1 and 50:1 for LLDPEs. In addition the film is stretched transversely by between 1.5:1 and 4:1.

The molecular orientation imposed during extrusion is thus modified by the drawing and blowing process in the film bubble. Generally the extrusion orientation is small compared with that resulting from melt drawing and does not influence significantly the final orientation.

Stress relaxation times in molten polyethylene are very short, so the imposed stresses resulting from the orientation are continuously being reduced by relaxation occurring in the bubble between the die and the freeze line. The rate of relaxation is largely dependent upon the temperature of the melt and the molecular weight of the polymer. At the freeze line the residual orientation and stresses are retained or frozen-in the film as the melt crystallises.

With narrow molecular weight distribution LLDPEs like *Alkatuff*, stress relaxation is very fast and the polymer has low extensional viscosity and a reduced tendency to strain-harden compared with *Alkathene* type LDPE. These differences mean that the imposed molecular orientation in LLDPE film will be much less than that obtained in an LDPE film.

EFFECT OF ORIENTATION ON TENSILE AND TEAR PROPERTIES

When the film is oriented in the machine direction (i.e. low blow-up ratio, high haul-off rate), it will have relatively high MD yield and tensile strengths with low MD elongation at break and low MD tear strength. Such a film would have low TD tensile strength but higher TD tear strength. The converse applies to a film with greater transverse direction orientation (high blow-up ratio); such a film has a more balanced orientation and often the tensile and tear strengths in the two directions are each similar in value.

The effects of blow-up ratio and output rate on the tensile and tear strengths are illustrated in Figures 30 and 31, for an *Alkathene* LDPE grade of MFI 2, density 0.921 g/cm^3. These figures show that blow-up ratio in particular has a significant influence on the MD tensile strength and TD tear strength, and that a blow-up ratio can be chosen to enable a balanced film to be produced.

The influences of blow-up ratio on the tear strength for some films produced from *Alkamax* mLLDPE are shown in Figure 3. This figure shows that tear strength in both directions decreases as the blow-up ratio is increased.

These graphs, while specific to the experimental extrusion conditions used, typify the property dependencies on extrusion conditions that can be expected in any blown film extrusion process.

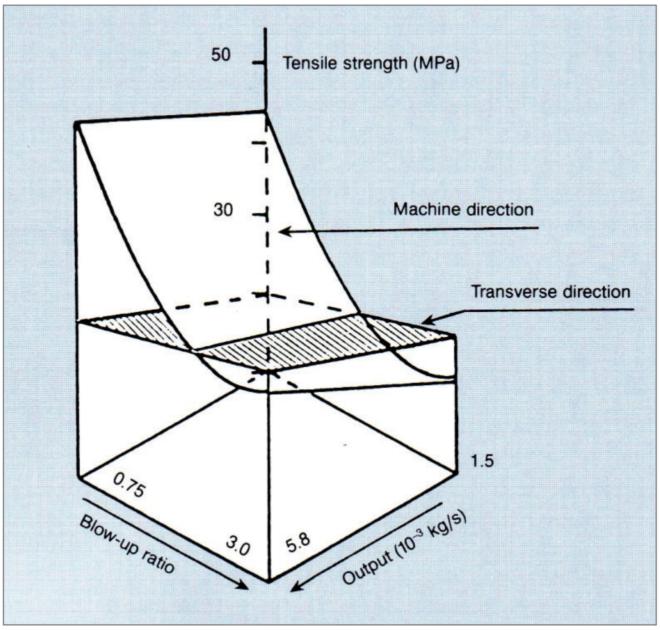

Figure 1: Variation of Tensile Strength with Blow-up Ratio and Output Rate of an *Alkathene* LDPE Grade of MFI 2.0 and Density 0.921 g/cm^3 (Film Thickness 38 micron)

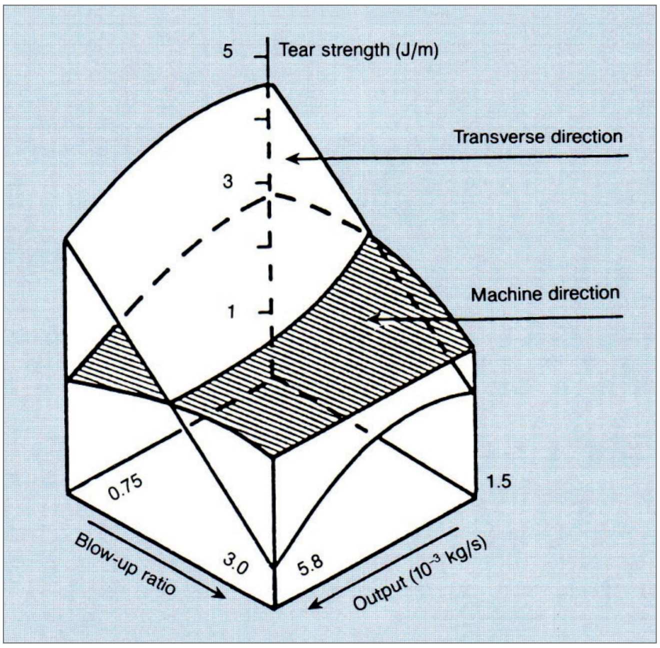

Figure 2: Variation of Tear Strength with Blow-up Ratio and Output Rate of an *Alkathene* LDPE Grade of MFI 2.0 and Density 0.921 g/cm3 (Film Thickness 38 micron)

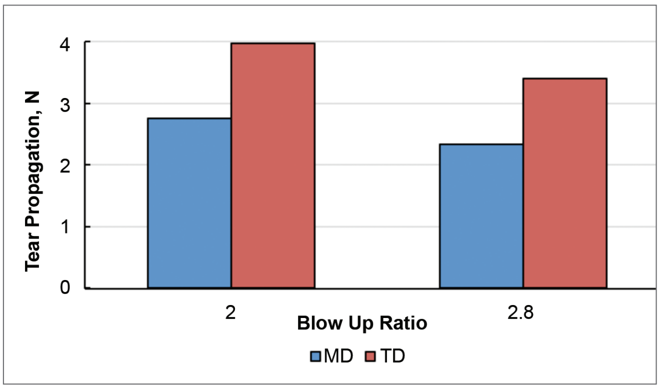

Figure 3: Effect of Blow-up Ratio on Tear Propagation for *Alkamax* mLLDPE Grade of MFI 1.0, Density 0.918 g/cm3 (Film Thickness 25 micron)

EFFECT OF ORIENTATION ON IMPACT PROPERTIES

The effects of orientation particularly influence the impact strength of the polyethylene film. Figure 4 shows the steady improvement in impact strength with increasing blow-up ratio and output rate for an *Alkathene* LDPE of MFI 2 and density 0.921 g/cm^3. Similar effects are observed with LLDPE polymers.

The most likely orientation to be frozen and retained in the film is that imposed just before the freeze line; orientation imposed earlier is partially or completely relaxed. Hence the order in which the machine and transverse drawing occurs in the drawing zone between the die and the freeze line will determine which one predominates, and which will have most influence on the mechanical properties of the film. If transverse drawing occurs just before the freeze line, then greater TD orientation is obtained. This will result in film with greatly improved impact strength.

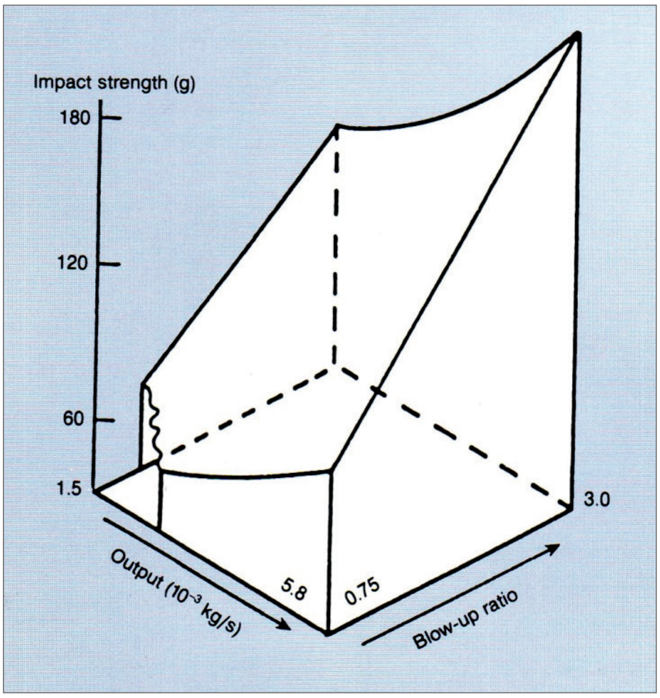

Figure 4: Variation of Impact Strength with Blow-up Ratio and Output Rate of an *Alkathene* LDPE Grade of MFI 2.0 and Density 0.921 g/cm3 (Film Thickness 38 micron)

EFFECT OF BUBBLE SHAPE ON IMPACT PROPERTIES

The shape of the bubble gives an idea of the order in which drawing will take place. Figure 5 illustrates schematically the hypothetical modes of drawing in the bubble to give alternate bubble shapes. In diagram (a), melt drawing occurs simultaneously in both the machine and transverse directions with the former predominating and results in moderate impact strength. In diagram (b), machine direction drawing predominates before the freeze line, resulting in poor impact strength. In diagram (c), the high impact strength stalk-shaped bubble is illustrated; here transverse drawing is predominant just before the freeze line. Since very little further relaxation can take place before the film is 'frozen', a high level of molecular orientation in the transverse direction is retained in the film. See also Figure 38.

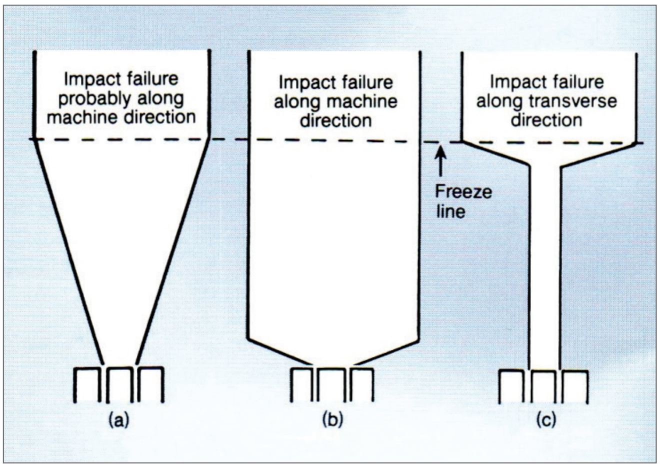

Figure 5: Hypothetical Modes of Drawing of a Film Bubble

The bubble shape in Figure 5 (c) is standard for HDPE film. A higher level of transverse orientation is critical for HDPE to avoid 'splitty' film. The neck height is recommended to be five to eight times the die diameter.

These changes in bubble shape and drawing behaviour become less significant at low blow-up ratios since a smaller amount of transverse drawing takes place. Although the drawing behaviour will be affected by the type of polymer being used, it can be controlled by adjustment of extrusion conditions such as freeze line distance, blow-up ratio, die gap, output rate, and cooling arrangements. For example, the high impact bubble shape can be obtained by raising the freeze line distance at a given blow-up ratio or by increasing the output rate for a given freeze line distance, blow-up ratio and film thickness.

BALANCED MECHANICAL PROPERTIES

By comparison of Figure 4 with Figure 1, the high impact resistance obtained at high blow-up ratios and high outputs, is associated with very low tear strength in the transverse direction. Hence a compromise must often be made in choosing operating conditions for the best balance of mechanical properties – approximately equivalent MD and TD tear strengths are obtained and a moderately high impact strength.

CRYSTALLISATION AND RATE OF COOLING

The crystalline structure imposed on polyethylene film during the cooling stage between the die lips and the freeze line is dependent on the density of the polymer and also on the rate of cooling. Fast cooling, i.e. a low freeze line, yields small spherulites, a low crystallinity and a low density. Slow cooling will lead to enhanced spherulitic growth and this will be greater for LLDPE under these conditions.

The crystalline structure has a marked effect on the mechanical properties and particularly the impact strength of the film. Any processing condition that causes faster cooling, for example, a lower freeze line distance, will lead to improved impact strength.

Decreases in film density caused by fast cooling rates will lead to reduced film stiffness, lower tensile strength and higher elongation at break. The effect on tear strength is less clear because of the masking by orientation effects.

With Alkatuff LLDPE, film properties will depend on crystallisation effects to a greater extent than with *Alkathene* LDPE and rapid cooling is to be preferred. This can be achieved with a low freeze line, higher output rates and higher extrusion temperatures.

SUMMARY OF EFFECTS OF PROCESSING CONDITIONS

Table 3 summarises the effects of processing conditions on the mechanical properties of *Alkathene* LDPE and *Alkatuff* LLDPE films. It should be noted that this table is only indicative, and responses may be different depending on the particular balance of orientation, relaxation and crystallisation effects. In particular, experience with *Alkamax* mLLDPE grades is still being developed.

Note that the elongation at break tends to respond in the opposite manner to the tensile strength.

Table 1: Effects of Varying Processing Conditions on Mechanical Properties of LDPE and LLDPE Film

For an increase in Processing Condition	Effect on Mechanical Properties			
	Tensile Strength	Impact Strength	Tear Strength (*Alkathene* LDPE, *Alkatuff* LLDPE)	Tear Strength (*Alkamax* mLLDPE)
Blow-up ratio	Decreases in MD Increases slightly in TD More balanced film	Increases, especially at high freeze line distance	Increases or is constant in MD Decreases in TD More balanced	Decreases
Melt temperature	Tends to decrease	Increases	Decreases	Decreases
Freeze line distance	Relatively insensitive	Variable	Increases in MD Decreases in TD	Relatively insensitive
Output rate	Small increase in TD	Increases markedly	Decreases both directions	MD increases
Die Gap	Little effect	Decreases	Little effect	Relatively insensitive
Stalk-shaped bubble	Decreases in MD Increases in TD	Increases	Decreases in TD	Unknown
Film thickness (haul-off rate)	Relatively insensitive	Increases	Increases in MD Decreases in TD More balanced	Decreases

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