# Effects of the Processing Conditions and Blending with Linear Low-Density Polyethylene on the Properties of Low-Density Polyethylene Films

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SYNOPSIS

Effects of blending low-density polyethylene (LDPE) with linear low-density polyethylene (LLDPE) were studied on extrusion blown films. The tensile strength, the tear strength, the elongation at break, as well as haze showed more or less additivity between the properties of LDPE and LLDPE except in the range of 20–40% where synergistic effects were observed. The LLDPE had higher tensile strength and elongation at break than did the LDPE in both test directions, as well as higher tear strength in the transverse direction. The impact energies of the LLDPE and the LDPE were approximately the same, but the tear strength of the LLDPE was lower than that of LDPE in the machine direction. The comparative mechanical properties strongly depend on the processing conditions and structural parameters such as the molecular weight and the molecular weight distribution of both classes of materials. The LLDPE in this study had a higher molecular weight in comparison to the LDPE of the study, as implied from its lower melt flow index (MFI) in comparison to that of the LDPE. The effects of processing conditions such as the blow-up ratio (BUR) and the draw-down ratio (DDR) were also studied at 20/80 (LLDPE/LDPE) ratio. Tensile strength, elongation at break, and tear strength in both directions became equalized, and the impact energy decreased as the BUR and the DDR approached each other.

## INTRODUCTION

Blends of low-density polyethylene (LDPE) and linear low-density polyethylene (LLDPE) have gained such importance that they have been commercialized.[1,2] LLDPE is added to LDPE owing to its superior mechanical properties, e.g., higher tensile strength, elongation at break, and impact strength. In addition to this, it allows a higher degree of down-gauging of the LDPE films.[3-5] On the other hand, addition of LDPE to LLDPE modifies its extensional viscosity and improves the productivity in film blowing.[6]

Another important reason of blending LDPE and LLDPE is to be able to use the conventional LDPE film-blowing apparatus without modification, which otherwise would need to be altered to process LLDPE. Blends of up to a 40/60 (LLDPE/LDPE) ratio can be processed in the conventional LDPE film-blowing equipment.[7-10]

The first part of the study was undertaken to observe the effects of blending LLDPE with LDPE on the mechanical properties such as tensile, tear, and impact as well as haze. In the second part of the study, a 20/80 LLDPE/LDPE blend was processed in a conventional LDPE film-blowing machine and the effects of the operating parameters such as the blow-up ratio (BUR) and the draw-down ratio (DDR) on the mentioned properties were observed.

## EXPERIMENTAL

### Materials

Commercial grades of LDPE and LLDPE were used in this study. Some characteristics of the materials use are given Table I.

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**Table I Properties of the LDPE and LLDPE**

| Property | ASTM Method | Unit | LDPE | LLDPE |
|---|---|---|---|---|
| MFI | D-1238 | g/10 min | 1.2 ± 0.3 | 1 |
| Density | D-1505/D-792 | g/cm$^3$ | 0.923 | 0.920 |
| Vicat point | D-1525 | °C | 95 | 103 |

## Film Preparation

In the first part of the study, the LLDPE content of the blends were varied from 0 to 100% using a machine with a mixing head capable of extruding LLDPE. The pellets of LLDPE and LDPE were premixed manually before feeding to the hopper for all the films prepared. The BUR, the DDR, the melt temperature, the screw speed, and the cooling air flow rate were kept constant. The BUR was calculated from the following formula:

$$\text{BUR} = \frac{2 \times \text{lay flat width}}{\pi D} \qquad (1)$$

where $D$ is the (die) bubble diameter. The DDR was calculated from

$$\text{DDR} = \frac{\text{Die gap}}{\text{Film thickness} \times \text{BUR}} \qquad (2)$$

In this part of the study, the die diameter was 8.0 cm, the lay flat width was 42 cm, and the die gap was 0.1 cm. Thus, the BUR was 3.34 and the DDR was 7.48 as calculated from eqs. (1) and (2). The films obtained had an average thickness of 40 microns. The results on these films are shown in Figures 1–4.

In the second part of the study, the LLDPE/LDPE ratio was kept at 20/80. The blends were extruded on a machine with a conventional LDPE screw. The melt temperature, the screw speed, and the cooling air-flow rate were kept constant. Films were prepared at BURs of 0.77, 1, 1.5 and 2. The

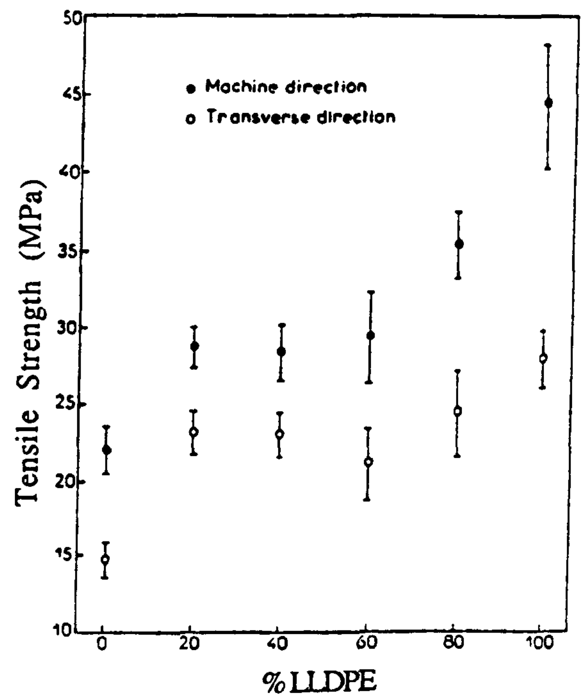


**Figure 1** Tensile strength of the LLDPE/LDPE blends in both directions as a function of the LLDPE content.

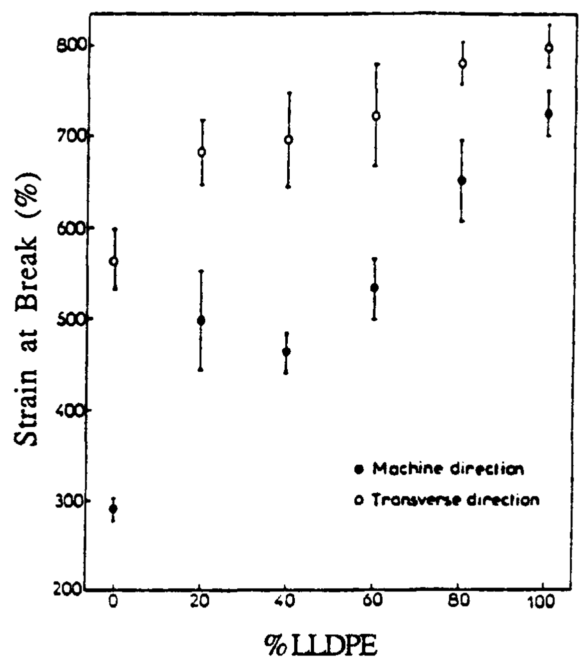


**Figure 2** Elongation at break of the LLDPE/LDPE blends in both directions as a function of the LLDPE content.

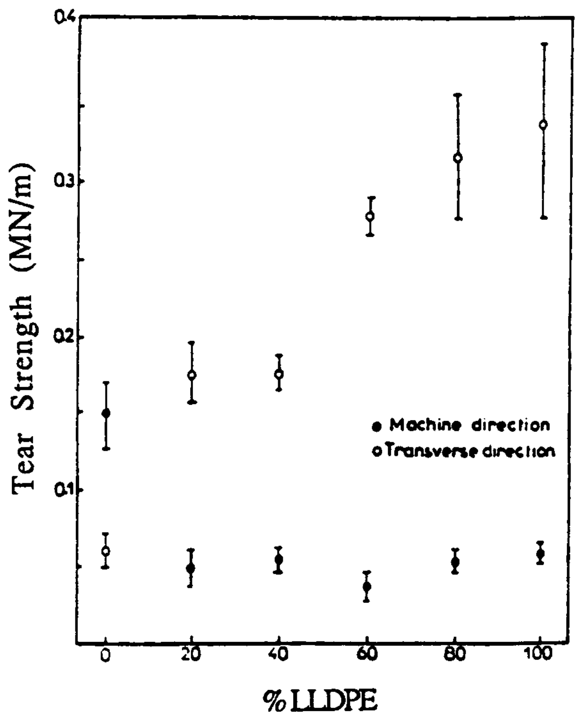


Figure 3 Tear strength of the LLDPE/LDPE blends in both directions as a function of the LLDPE content.

DDR was adjusted to give a constant average film thickness of 40 microns. The results on these films are shown in Figures 5–8.

### Testing

Tensile tests were done according to British Standards 2782 Method 301 on rectangular films that had dimensions of 50 × 15 mm. The crosshead speed was 325 mm/min. Tear tests were done on an Elmendorf testing apparatus according to ASTM D-1922-61T. In these tests, the direction of crack propagation was identified as the direction of the test. Impact strength was also measured on an Elmendorf apparatus according to ASTM D3420-75. The data on tensile, tear, and impact tests were obtained on eight specimens, and 90% confidence intervals are shown in Figures 1–8. Haze was measured following British Standards 2782 Part 5 (1970). Haze data were obtained on five samples, and the averages are reported.

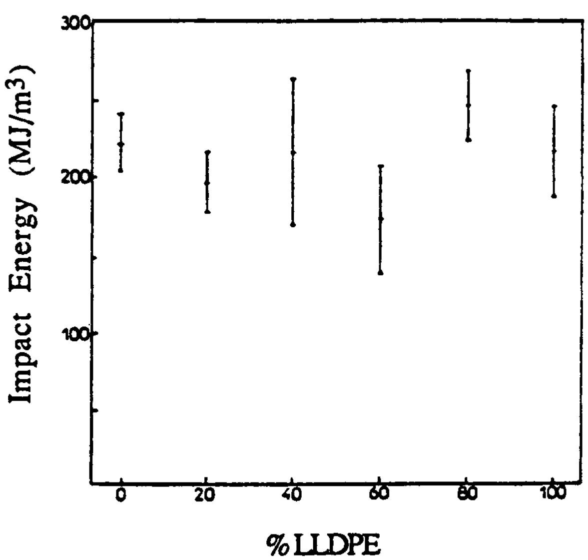


Figure 4 Impact energy of the LLDPE/LDPE blends as a function of the LLDPE content.

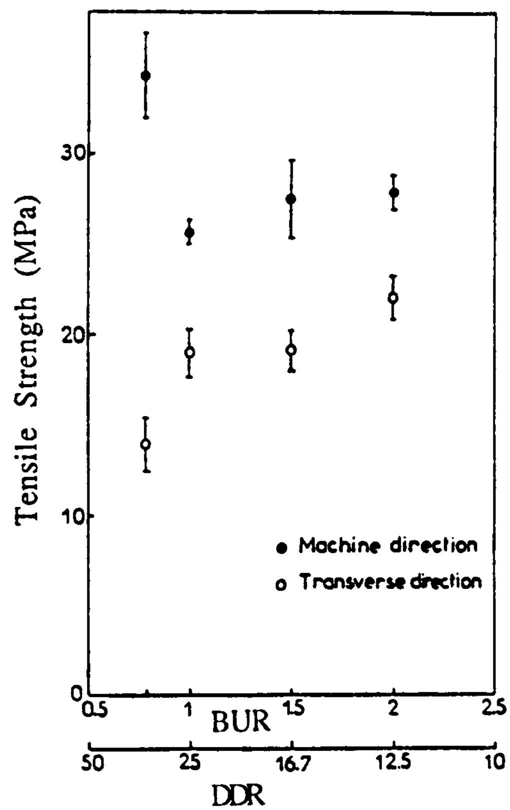


Figure 5 Tensile strength of the 20/80 (LLDPE/LDPE) blend as a function of the blow-up ratio and the draw-down ratio.

## RESULTS AND DISCUSSION

### Effects of Blending

The results of the tensile tests are shown in Figures 1 and 2. At this BUR (3.34) and DDR (7.48), the tensile strength in the machine direction is higher than is the tensile strength in the transverse direction for all the blends studied. The strain at break

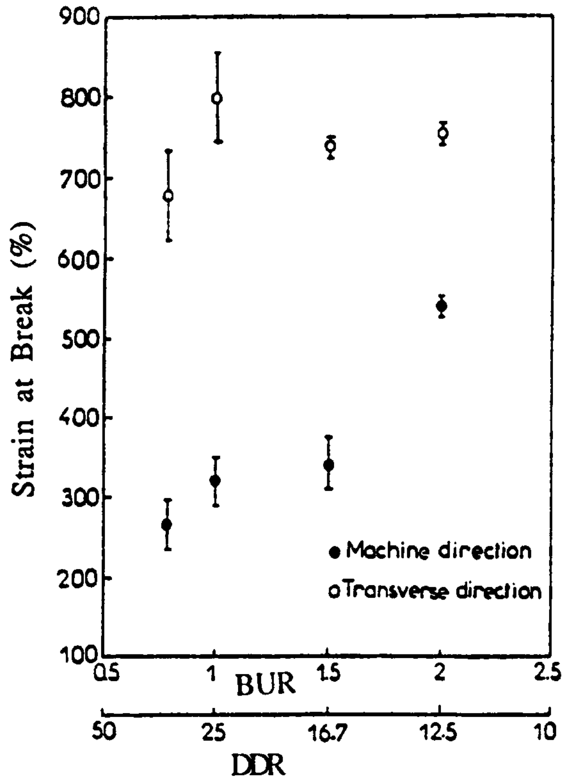


**Figure 6** Elongation at break of the 20/80 (LLDPE/LDPE) blend as a function of the blow-up ratio and the draw-down ratio.

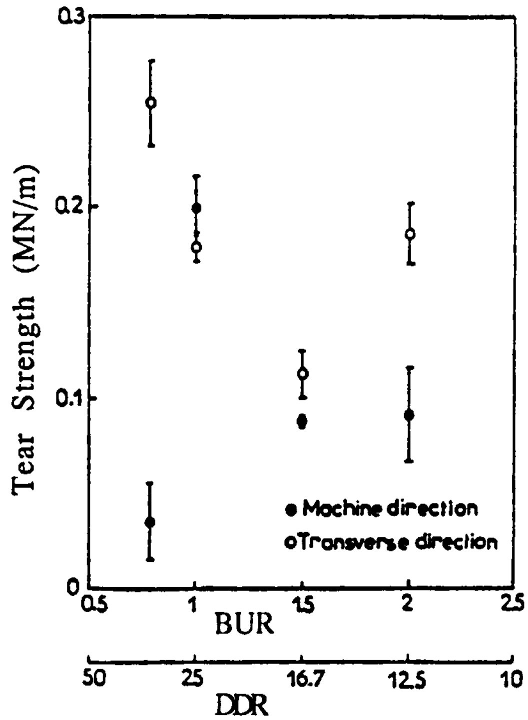


**Figure 7** Tear strength of the 20/80 (LLDPE/LDPE) blend as a function of the blow-up ratio and the draw-down ratio.

shows the opposite trend, i.e., it is higher in the transverse direction than in the machine direction. These effects can be attributed to higher degree of orientation in the machine direction than in the transverse direction.

It is observed that the LLDPE has higher tensile strength and higher strain at break than does the LDPE in both directions. However, these comparative results should not be generalized to all LLDPE and LDPE materials, and the effects of the molecular weight and the molecular weight distribution should be considered. In this study, the LLDPE has a lower MFI than does the LDPE, implying a higher molecular weight. This is in line with the tensile test results. The tensile properties of the blends are in accordance with the additivity rule except at 20 and 40% LLDPE contents in which all the tensile properties studied are higher than expected from simple additivity. Similar results are reported in the literature.[11,12]

In Table II, percent haze is shown as function of LLDPE content. Haze undergoes a maximum between 20 and 40% LLDPE content in accordance with the results on tensile properties. In the liter-

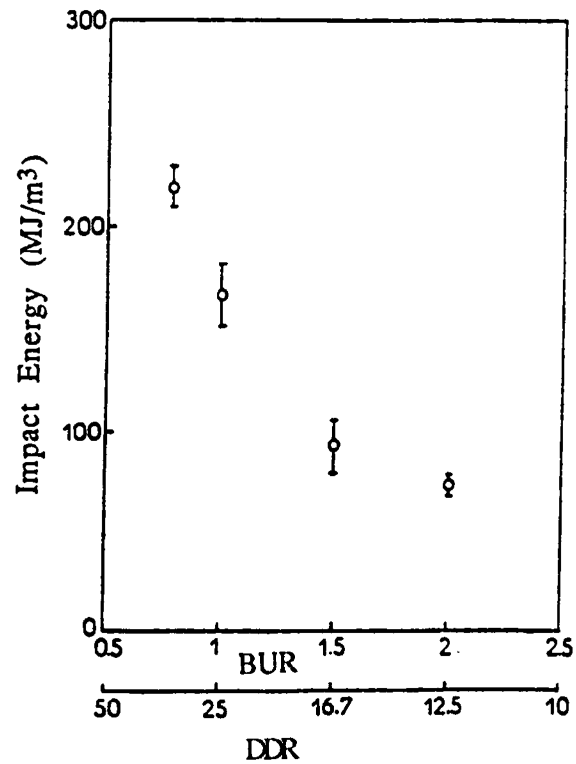


**Figure 8** Impact energy of the 20/80 (LLDPE/LDPE) blend as a function of the blow-up ratio and the draw-down ratio.

ature, it is reported that LLDPE/LDPE blends are, in general, not miscible based on detailed rheological studies that included the frequency relaxation spectrum.[13]

The tear strengths of the blends are shown in Figure 3. The LLDPE has higher tear strength than does the LDPE in the transverse direction. The tear strength in the transverse direction shows simple additivity for all the blends except for 20% LLDPE content, at which the tear strength in the transverse direction is higher than expected from additivity. The tear strength of the LLDPE is lower than is the tear strength of the LDPE in the machine direction. The linear tie chains of the LLDPE would orient mainly in the machine direction, since the DDR is higher than is the BUR. This may lead to low tear strength in the machine direction in the LLDPE. However, since the tie chains of the LDPE contain long-chain branching, they would not exhibit as perfect orientation in the machine direction as the tie chains of the LLDPE would. Thus, the tear strength of LDPE in the machine direction could be higher than that of LDPE. The LLDPE/LDPE blends have machine direction tear strengths that are close to that of LLDPE.

In Figure 4, the impact energies of the blends are shown. The LLDPE, the LDPE, and the blends have approximately the same impact strength. The impact strength is influenced by tear strengths in both directions, but probably more by the tear strength that is lower, since under impact conditions cracks can propagate in the direction of least resistance. In Figure 3, it is seen that while the average tear strength increases with the LLDPE content the lower tear strength is approximately constant. In view of this discussion, it is not surprising to see that the impact strength is constant with respect to the LLDPE content.

### Effects of the Blow-Up Ratio and the Draw-Down Ratio

The effects of the BUR and the DDR are shown in Figures 5–8 for a blend that contains 20% LLDPE in films that have an average thickness of 40 microns. At low BUR and high DDR, the orientation in the machine direction is much higher than is the orientation in the transverse direction. Thus, in Figures 5 and 6, it is seen that the tensile strength is higher in the machine direction than in the transverse direction and the strain at break shows the opposite trend, i.e., it is higher in the transverse direction than in the machine direction. As the DDR and the BUR approach each other, the properties in both directions approach each other. When the BUR is equal to DDR, equal biaxial orientation would take place, which theoretically implies equal properties in both directions.

**Table II Haze (%) as a Function of the LLDPE Content (%) in the LLDPE/LDPE Blends**

| Haze | LLDPE (%) |
|---|---|
| 18.3 | 0 |
| 25.0 | 20 |
| 26.4 | 40 |
| 23.6 | 60 |
| 20.3 | 80 |
| 20.4 | 100 |

The data on Figure 7 on tear strength show some scatter, but, in general, the tear strength in the transverse direction is higher than that in the machine direction. This phenomenon can be explained by the fact that if the tie chains as well as the crystallites are oriented more in one direction there would be less resistance to crack propagation in that direction. In this study, the orientation in the machine direction is higher than is the orientation in the transverse direction (DDR is higher than BUR), thus the tear resistance in the machine direction is lower in comparison to the tear resistance in the transverse direction. Again, as equal biaxial orientation is approached, the tear strengths in both directions tend to be equal.

The impact strength is shown in Figure 8. It is higher when the DDR is much higher than the BUR, but it decreases as the orientation in both directions becomes equal. The impact energy decreases with increasing BUR. This can be partially attributed to the decrease in the lower tear strength with increasing BUR, as seen from Figure 7, except for the lowest BUR of this study. In Ref. 5, it was concluded that between BUR of 1.35 and 1.9, the variation in BUR had negligible effect on film properties. However, it is seen here that a larger range of BUR gives rise to considerable variation in the properties.

## CONCLUSIONS

The LLDPE of this study has higher tensile strength and higher strain at break than does the LDPE of this study in both directions. The tensile properties of the blends of LLDPE/LDPE show additivity except in the range of 20–40% LLDPE content, in which the tensile properties are higher, implying compatibility in this range. Haze exhibits a maximum in this range and further supports this implication. With increasing LLDPE content, the tear strength is improved only in the transverse direction, but it decreases in the machine direction. The impact strengths of all blends are approximately the same.

At constant LLDPE content of 20%, the tensile strength is higher, but the strain at break and the tear strength are lower in the direction of higher orientation. The properties in both directions approach each other as equal biaxial orientation is approached. The impact energy decreases as the orientation becomes more equal in both directions.

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