Conformable Biaxially-oriented Polypropylene - A breakthrough for The Self-Adhesive Label Industry

Dr Mike Taylor[(a)], Alasdair M[c] Ewen[(b)], Dr John Rasburn[(c)]

[(a)]Business Development Manager

Labels and Graphics Business Unit

[(b)]Senior Project Leader, R&D

[(c)]Project Leader, R&D

Innovia Films, R&D Centre

West Road, Wigton, Cumbria, CA7 9XX.

Abstract

The development of a conformable biaxially-oriented polypropylene film for label facestock applications is described. Comparisons are made between the new film and traditional polyethylene films used for flexible container labelling. Results are presented to show how BOPP films with the high strength, stiffness and clarity associated with typical BOPP label facestock films, can now be prepared with the additional and conflicting property of conformability and squeeze-ability.

Introduction

Over the last 12 years there has been exceptional growth in the use of biaxially oriented polypropylene (BOPP) films as facestock materials for self-adhesive labels. In particular, bubble-manufactured BOPP has brought a multitude of attributes to label facestock producers. The benefits of bubble-BOPP are realised throughout the whole value chain, from the adhesive-laminator right through to the end-user. The inherent properties of polypropylene allow it's use in a wide range of demanding applications where labels are required to be resistant to water, oils, fats, bases, acids or salts or combinations of these aggressive agents. In their oriented state, the molecular alignment of the long polypropylene molecules gives rise to high stiffness and strength. This results in high performance of BOPP labels in the areas of printing (good control of register), die-cutting (excellent label edge appearance and even die-wear), matrix-stripping (high tensile strength results in fewer web-breaks) and in dispensing, where the high bending stiffness of BOPP allows high speed dispensing without the risk of "missing-labels".

Currently, these stiff, non-conformable BOPP films find widespread usage in glass bottle labelling or on rigid plastic containers and bottles. Their high clarity and strength have been key success factors in producing labels of high aesthetic quality, which can be dispensed at high speeds onto semi-rigid plastic containers or glass bottles. However, these film types have not found wide spread application in the labelling of squeeze-able containers due to their reduced performance in squeeze testing, where edge-lifting, film creasing and adhesive pull-off often occurs. This restricts the use of BOPP in such markets as Health and Personal Care which demand a pristine label appearance throughout the lifetime of a labelled container.

Indeed, it is somewhat a conflict of requirements to consider the use of BOPP as a deformable or squeeze-able label facestock - traditionally the domain of polyethylene (PE) films. The very reason for orienting a film is to impart considerably higher stiffness to a film. However the widely used PE films, whilst having the conformability required for squeeze-container labelling, generally suffer from poor clarity (haze) and need to be considerably thicker than BOPP in order to effect efficient dispensing performance. Both of these factors limit their ability to offer the no-label-look.

Recently-developed technology at Innovia Films however is set to completely change this picture. Realising the need for an enhanced no-label-look on clear labelled flexible containers, which has major appeal to product marketers in the packaging field, Innovia Films have developed bubble-BOPP technology which can deliver clear, high tensile strength label films, but with reduced moduli. These films, designated "Rayoface™ CZPA", are designed to have the resilience and conformability/ squeeze-ability of polyethylene type label films, with the added advantages associated with BOPP: high gloss, high clarity and lower thickness whilst maintaining dispensing performance.

This article describes the evolution of Rayoface^{TM} CZPA and compares it's characteristics to those of traditional conformable label face-stock films. In order to simplify discussion, the term "conformable" is used throughout to describe the squeeze-ability or conformability of a label.

Evolution of Rayoface^{TM} CZPA

With a remit to develop a conformable version of BOPP for labelling applications, the biggest challenge was to develop a film with a low modulus, but manufactured by a process which is designed to impart high modulus and strength. Initial attempts focussed on reducing the overall extent of orientation, but the modulus reductions achieved were insufficient to impart any degree of conformability to the BOPP films. Without an obvious process-based solution, attention was focussed on base polymer technology. By choosing polymers with inherently lower crystallinity and modulus than traditional extrusion grade polypropylenes, it has been possible to produce BOPP films with fundamentally the same level of the other important properties, whilst being more suitable for conformable label applications through their lower modulus.

In the early stages of the development 1% secant modulus measurements were made, to provide a relatively quick method of screening the variables. Figure 1 shows the differences in secant modulus achieved through different modifications to the process and formulation of the base film. For comparative purposes, a standard 85 micron PE control was included in the testing.

It can be clearly seen from Figure 1 that neither process modifications nor modulus-reducing additives were able to reduce the modulus to the level of the PE control. However, the lower crystallinity BOPP, sample CZPA, showed a significant reduction in secant modulus to a level comparable with the PE control.

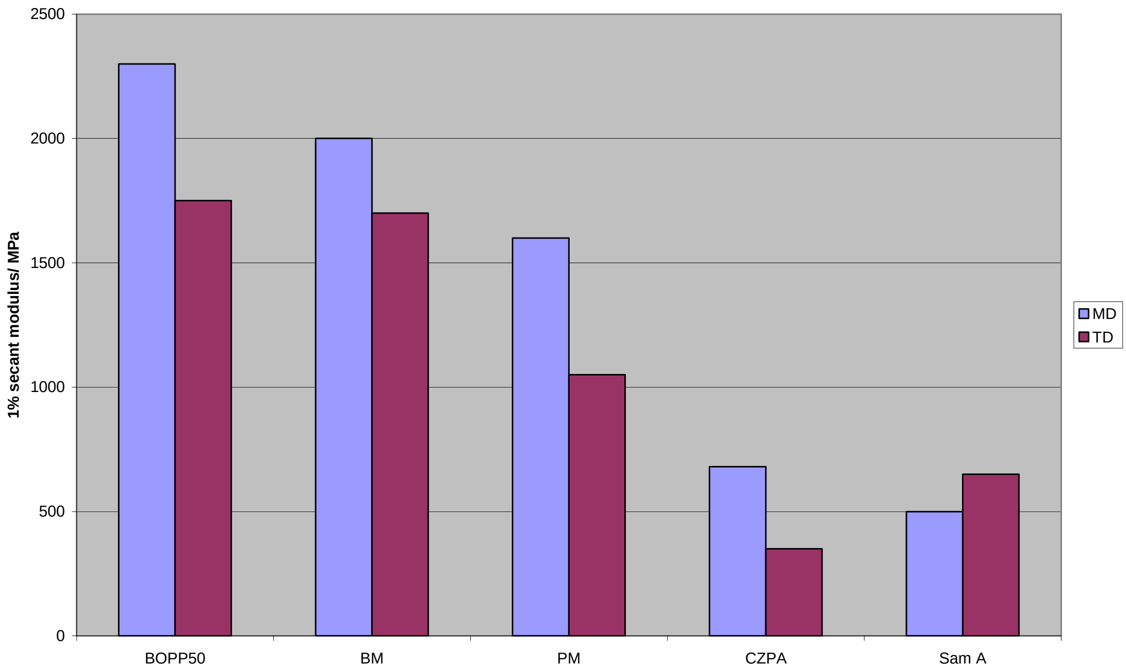

Figure 1 Secant moduli of process and polymer variants used in the development of CZPA. Key: BOPP50 - standard BOPP; BM Process-modified BOPP; PM BOPP with modulus-reducing additive; sam A "control" 85µm PE label film. MD - machine direction; TD - transverse direction.

The next stage was to evaluate whether CZPA was comparable to a range of commonly-used conformable films in dynamic mechanical testing.

Dynamic mechanical analysis

Two fundamental material parameters that underpin the performance of a label film are the storage modulus (E') and loss modulus (E"). For conformable label materials E' will govern the stresses required to deform/squeeze the label. E' should therefore be minimised in order to prevent "slippage" of the label at the adhesive-label or adhesive-container interface which can result in wrinkling of the label. There is however a lower bound of E' before other application aspects of the label have to be considered i.e. dispensability. The magnitude of E" determines the amount of mechanical energy dissipated (as heat) on deforming the label. Again E" should be minimised to ensure that the label can recover to its initial shape and dimensions on removal of the load. If this does not happen then again the label has the potential to "wrinkle" or "crease".

Both E' and E'' can be readily measured using Dynamic mechanical analysis (DMA). DMA is a technique employed to characterise materials in terms of their modulus, elasticity, viscosity, damping behaviour and relaxation phenomena (such as glass transition temperature). Each of these parameters can be monitored as a function of strain, rate of strain, temperature and oscillating frequency.

In a DMA test, an oscillating strain (typically sinusoidal) is applied to a sample and the resulting stress developed in the sample is measured. For a linear viscoelastic material the stress and strain will both vary sinusoidally, but the stress and strain will be out of phase with respect to each other. The stress signal can then be separated into two components; an elastic stress which is in phase with the strain and a viscous stress, which is 90^o out of phase with the strain. The stress-strain relationship can therefore be defined by a modulus E' which is in phase with the strain and a quantity E'' which is 90^o out of phase. Because it is in phase with the strain, E' is often called the storage modulus and it defines the energy stored in the specimen due to the applied strain. The modulus E'' which is out of phase defines the dissipation of energy and is often called the loss modulus.

DMA testing on CZPA, a standard BOPP control and a range of commonly-used conformable labelstock films, was performed using a TA Instruments DMA Q800 in tensile mode. Dynamic storage and loss moduli data were obtained for each sample of film, at 25°C and at a frequency of 3Hz, and the results are represented graphically in Figures 2 and 3.

Figure 2 clearly shows the lower storage modulus of the conformable films, when compared to a standard BOPP. The storage modulus of CZPA is considerably lower than the BOPP standard and is more balanced in both MD and TD compared to the other conformable films.

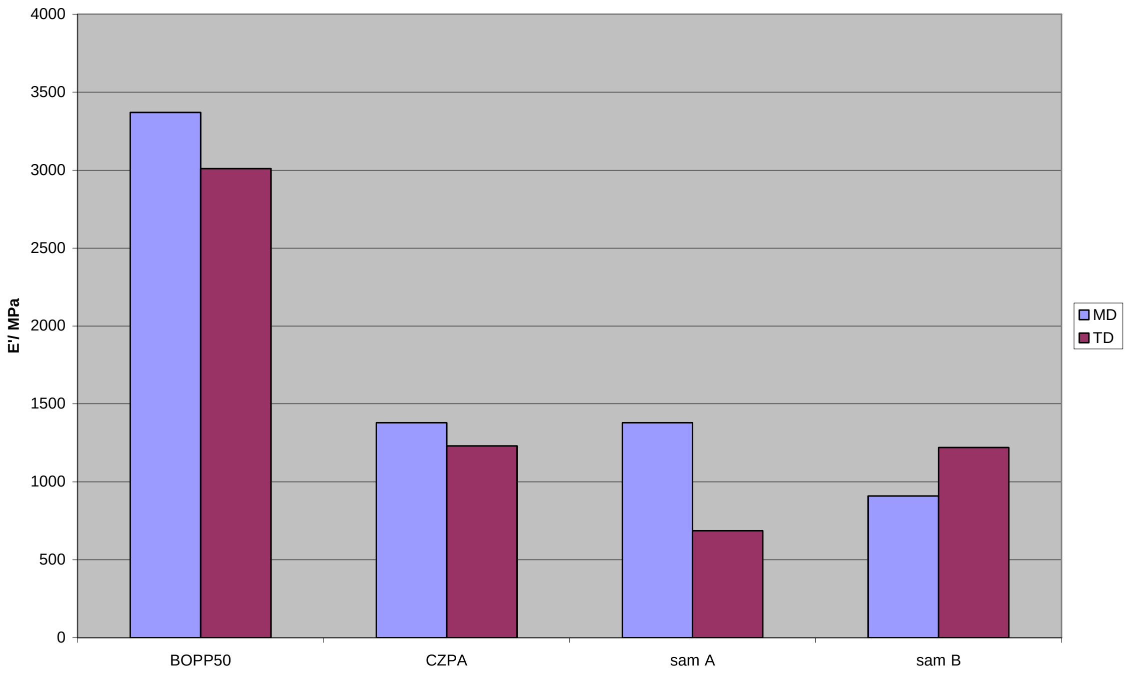

Figure 2 MD and TD storage modulus, E' of CZPA and a range of label face-stock films. Key: sam A and B - commonly-used conformable label films; BOPP50 - standard BOPP.

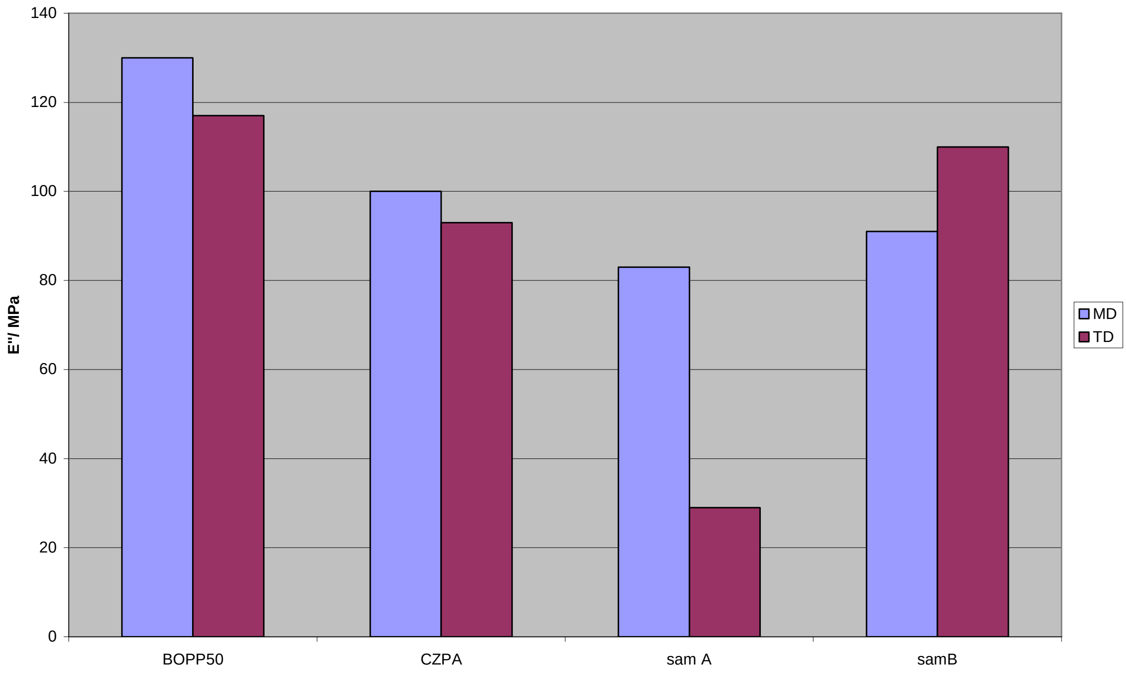

Figure 3 MD and TD loss modulus, E'' of CZPA and a range of label face-stock films. Key: sam A and B - commonly-used conformable label films; BOPP50 - standard BOPP.

The loss modulus of CZPA is approximately 25% lower than standard BOPP in both the MD and the TD and is comparable in magnitude to that of conformable film sample B. CZPA's performance as a conformable label would thus be expected to match that of sample B, a commonly used conformable label film. Sample A has the lowest loss modulus of all the films tested in both MD and TD and would therefore be expected to easily recover its original shape when subjected to dynamic deformation.

Functional Squeeze Testing

In order to further define the prospects for CZPA as a conformable label face-stock, it was necessary to simulate the end-use performance of the film as a label on a squeeze-able container. Films from DMA testing were tested for their suitability as conformable labels by conducting squeeze tests using a motor-driven reciprocating arm - a development of a textile durability testing apparatus. The squeeze testing apparatus is shown in Figure 4.

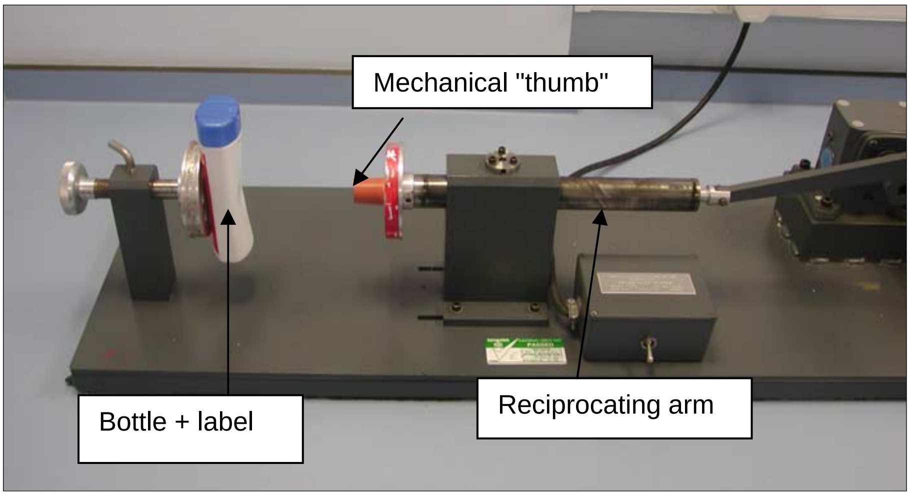

Figure 4 Dynamic squeeze testing apparatus used to rank the conformability of developmental films. The mechanical thumb is operated by a motor-driven reciprocating arm.

Films were coated with transfer adhesive and cut to the following dimensions which typify their size in end-use: 43mm-MD x 118mm-TD. The "Labels" were adhered to empty HDPE shampoo bottles and the labelled bottles were conditioned for 48 hours at 25^{o}C. Bottles were squeezed 60 times wall to wall, using the squeeze test apparatus. After each set of 10 squeezes the labels were examined for any visual defects. Figure 5 shows the results of the squeeze tests, comparing label performance in terms of creasing and edge-tunnelling. The key to the performance rankings are described in Table 2.

Figure 5 shows CZPA to perform exceptionally well in squeeze testing. In comparison with BOPP50, CZPA does not observe any creasing/ edge tunnelling even after 60 wall-to-wall squeezes, whereas BOPP50 shows tunnelling after 20 squeezes and creasing after 50 squeezes.

When compared to films already used in squeeze-able container labelling, CZPA out-performs both sample A and B, showing no signs of tunnelling or creasing even after 60 wall-to-wall squeezes. If a ranking of 1 or 2 can be deemed acceptable for a conformable label, CZPA compares favourably with both of the commonly-used conformable label films.

Table 2 Squeeze test performance rankings

Ranking	Description
1	No defects on label. Label in good condition.
2	1 or 2 separate areas of edge lift or tunnelling. No creasing on label.
3	More than 2 areas of edge lift/tunnelling. No creasing on label.
4	More than 2 areas of edge lift/tunnelling. Creases starting to appear on label.
5	Multiple areas of edge lift/tunnelling all around label and severe creasing across label.

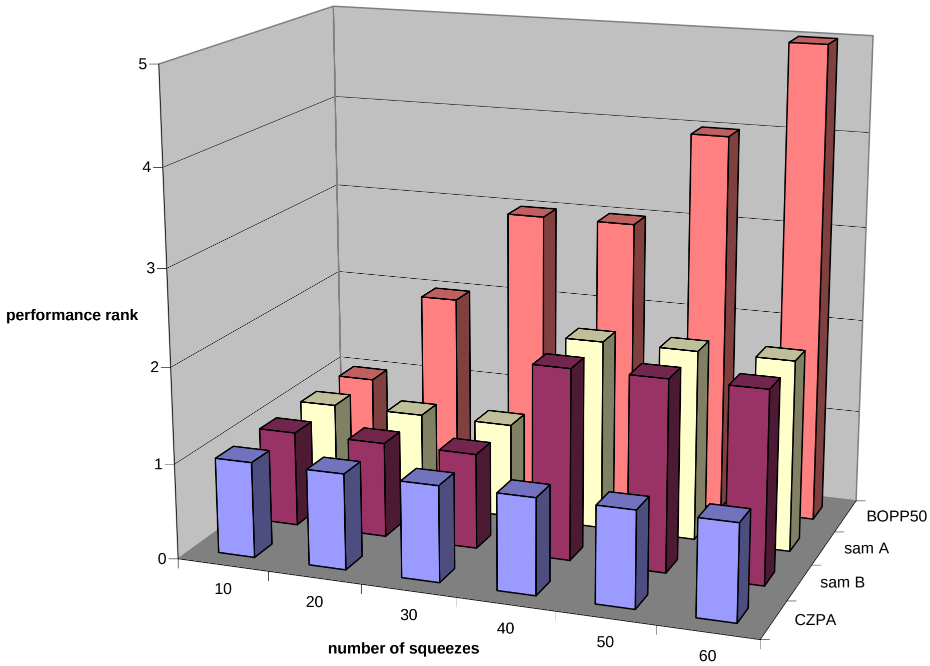

Figure 5 Results from automatic squeeze testing.

Comparative testing of CZPA versus established conformable label films

It has so far been shown that CZPA has a low dynamic loss modulus, which translates into a high performance in squeeze testing. However, a film needs to perform in a number of other areas to be successful as a pressure-sensitive adhesive facestock for labelling of bottles/ containers. In particular, the high speed adhesive coating operations used to apply adhesives to a facestock demand that films must be held under tension without deforming. In addition, the film needs to be die-cut to specific label shapes and also it needs to be printable by traditional label printing processes such as UV Flexography, UV screen etc.

The physical properties of a film can often give a good indication of how it will perform as a label facestock. In this present study, the tensile strength and elongation at break of CZPA was compared with BOPP50, sample A and sample B.

Tensile Performance

Tensile testing of films was carried out according to ASTM D882 and the results are shown in Figures 6 and 7. Clearly, the tensile strength of CZPA is considerably higher than all of the other conformable films tested, whilst being only slightly lower than the non-conformable BOPP50. Samples A and B showed the lowest tensile strength values in both the MD and TD.

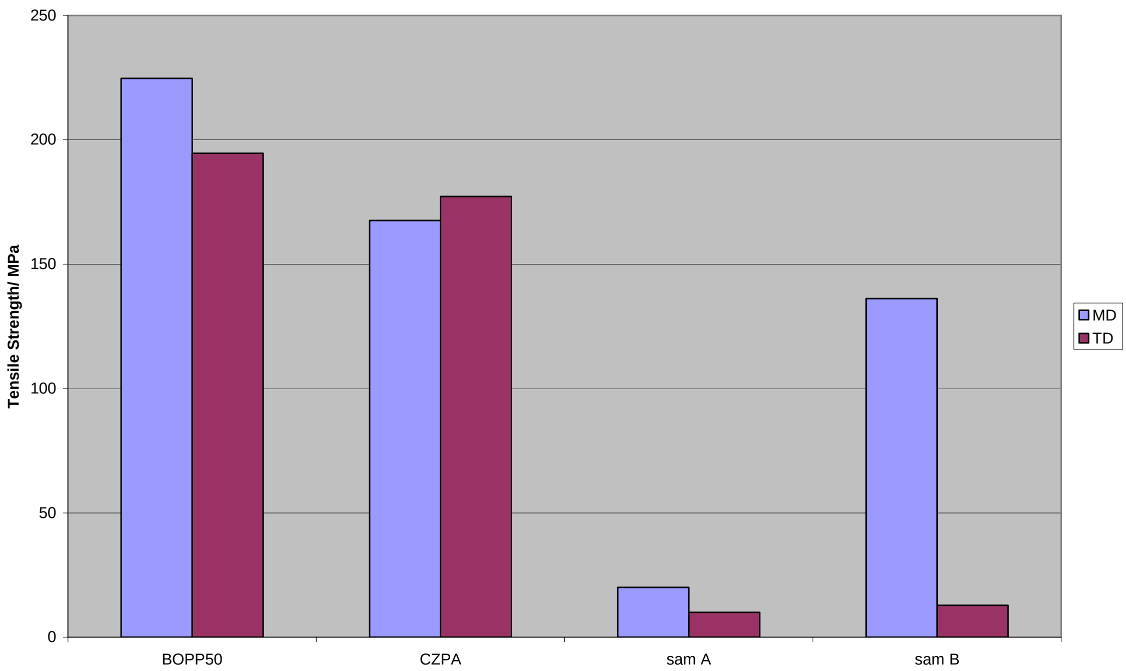

Figure 6 Tensile strength of CZPA compared with standard BOPP and various commonly-used conformable label films.

The higher level of tensile strength of CZPA would suggest that the film will be able to withstand higher tensions during conversion than the other conformable films. In addition, the balance of strength in the MD and TD for CZPA is not apparent in the other films. Balanced tensile strength properties give rise to high film dimensional stability. It is expected therefore, that CZPA will exhibit better register control during printing, when compared to the other conformable films.

The elongation at break of CZPA is similar to BOPP50 and is comparable with that of sample B. Sample A showed the greatest elongation at break value. When compared to CZPA the conversion stability of samples A and B would be expected to be considerably lower.

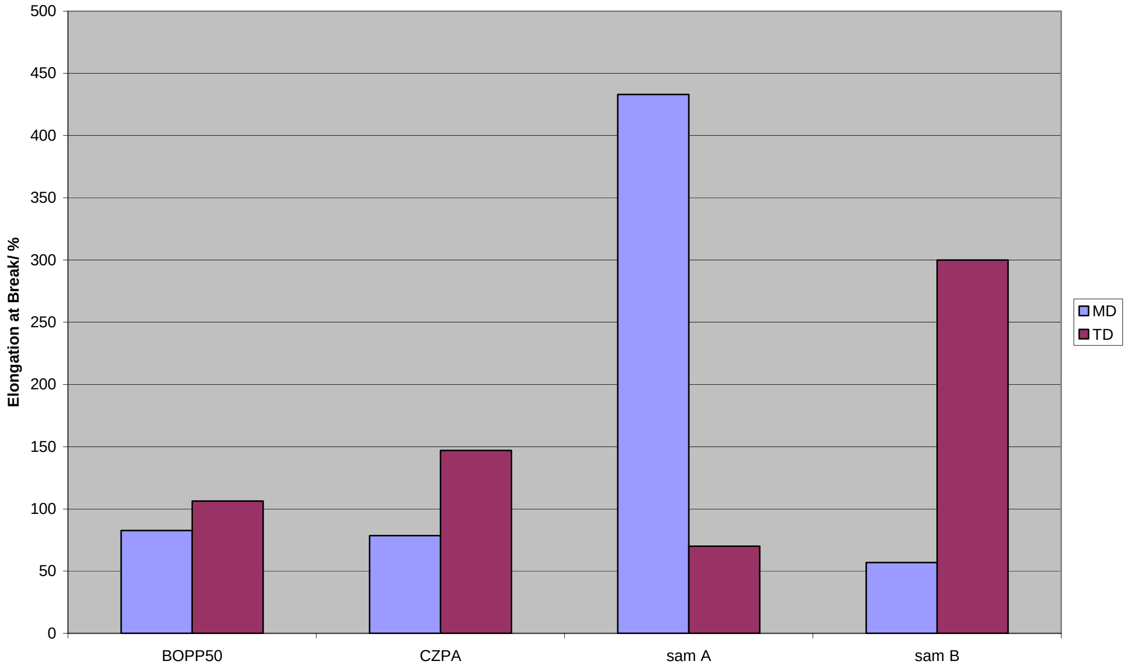

Figure 7 Tensile Elongation at break of CZPA compared with standard BOPP and various commonly-used conformable label films.

When compared to the other conformable films the MD elongation of CZPA is at a comparably low level but is more balanced, with all other conformable films showing non-balanced elongation at break.

Haze and Gloss

The narrow-angle haze of CZPA, BOPP50 and samples A and B were tested according to ASTM D1003. Table 3 lists the results from haze tests.

Table 3 Haze Results for CZPA, BOPP50 and samples A and B

Film sample	Narrow angle haze %
BOPP50	3
CZPA	3
Sample A	12
Sample B	11

Table 3 shows that the haze of CZPA is comparable with that of a standard BOPP labelstock film and is considerably lower than that of the commonly-used conformable films (samples A and B). This difference in optical clarity should allow for an improved "no-label-look" when using the film as a label facestock in clear container labelling.

Print Performance

CZPA film incorporates a proprietary top coating which has been proven to give a high degree of print performance. The top-coat is suitable for printing by a wide variety of printing processes including offset screen, letterpress and flexography and gives particularly good results with UV curing inks. An additional benefit of the top coat is it's resistance to hot and cold water immersion, which is am important consideration when labelling bathroom or under-the-sink products.

Conclusions

It has been demonstrated that balanced biaxially-oriented BOPP films can now be manufactured having all the recognised characteristics of standard BOPP label films, but with the additional conformability needed for the labelling of flexible/ squeeze-able containers.

This breakthrough in Label film technology is a major step for BOPP in terms of it's ability to be used in areas traditionally dominated by polyethylene label films and represents a significant opportunity for the pressure-sensitive label industry to utilise the proven benefits of BOPP in application areas thus far not represented by BOPP films.