

CHAPTER IV

RESULTS AND DISCUSSION

In this research, the effect of HDPE on mechanical and physical properties of LLDPE/LDPE blown films was studied. Two grades of HDPE with different melt flow indices of 0.04 and 0.7 g/10min (hereafter, HDPE1 and HDPE2, respectively) and two types of LLDPE, i.e., Ziegler-Natta and metallocene-catalyzed resins (hereafter, zn-LLDPE and m-LLDPE, respectively) were used.

4.1 Effect of HDPE content

In this part, LDPE content in ternary blend blown film was kept constant at 15%. The remaining components composed of HDPE and LLDPE, in which HDPE was varied from 5 to 30%. Later, the blends were fabricated into films on a blown-film extrusion line based on the same processing conditions (see Experimental Section), except for the blown film from the blend containing 30% HDPE1 and 55% zn-LLDPE. In such a case, the bubble of the blown film was not stable as previously mentioned, so the screw speed had to be reduced from 35 to 27 rpm. Despite the setting, the surface of the film obtained from the particular blend was very rough.



4.1.1 Effect of HDPE content on mechanical properties of LLDPE/LDPE/HDPE blown film

4.1.1.1 Effect of HDPE content on Young's modulus

Figures 4.1 and 4.2 show Young's modulus of the obtained LLDPE/LDPE/HDPE blown films in both the machine and the transverse directions as measured by universal testing machine. Clearly, the Young's modulus of the blown films in both the machine and the transverse directions increased with increasing HDPE content in the blown films. Relatively, HDPE is more crystallizable than both LDPE and LLDPE, thus increasing HDPE content in the blown films should result in an increase in the apparent crystallinity of the resulting films. Crystallites that are present within the film matrix act as physically crosslinking points, causing the matrix molecules to be less mobile.

A similar result was reported by Hatairat [6]. She prepared the blown films of HDPE-rich blend (0-40% LLDPE) and found that the stiffness of the resulting HDPE/LLDPE blown films decreased when LLDPE content increased. In other words, when HDPE content increased, the stiffness of the resulting HDPE/LLDPE blown films increased.

From Figures 4.1 and 4.2, blown films from the blends containing m-LLDPE, exhibited higher Young's modulus than the blown films from the blends containing zn-LLDPE in both directions. The m-LLDPE and zn-LLDPE used in this study had the same octene comonomer content and density but m-LLDPE had lower melt flow index, implying a higher molecular weight [17]. In addition, m-LLDPE had more uniform distribution of short chain branching along its molecules, causing it to blend more homogeneously with LDPE. Therefore, the blown films obtained from the ternary blend of m-LLDPE/LDPE/HDPE were stiffer than those from the ternary blend of zn-

LLDPE/LDPE/HDPE. As mentioned in the Introduction Section, stiffness is an important property for flexible packaging films; therefore, the increase in the Young's modulus of the blown films is preferred.

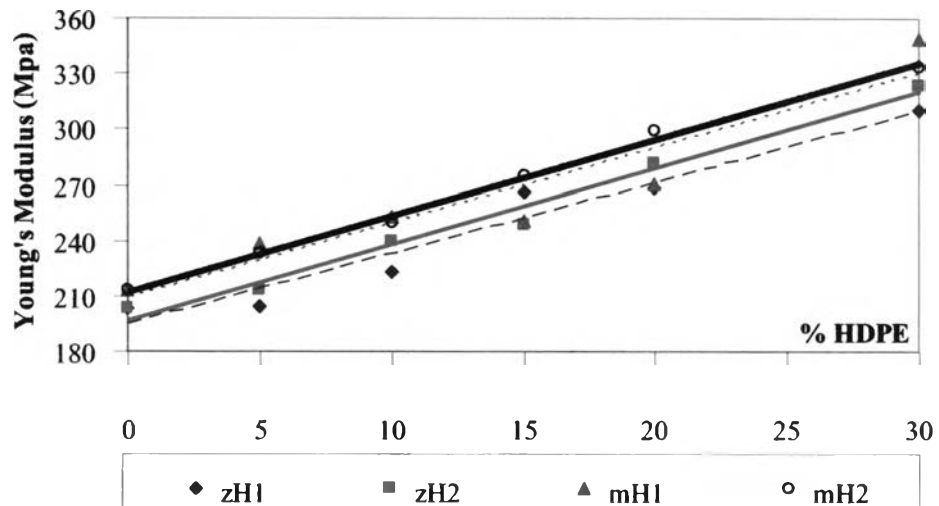


Figure 4.1 : Effect of HDPE content on Young's modulus in machine direction of LLDPE/LDPE/HDPE blown films.

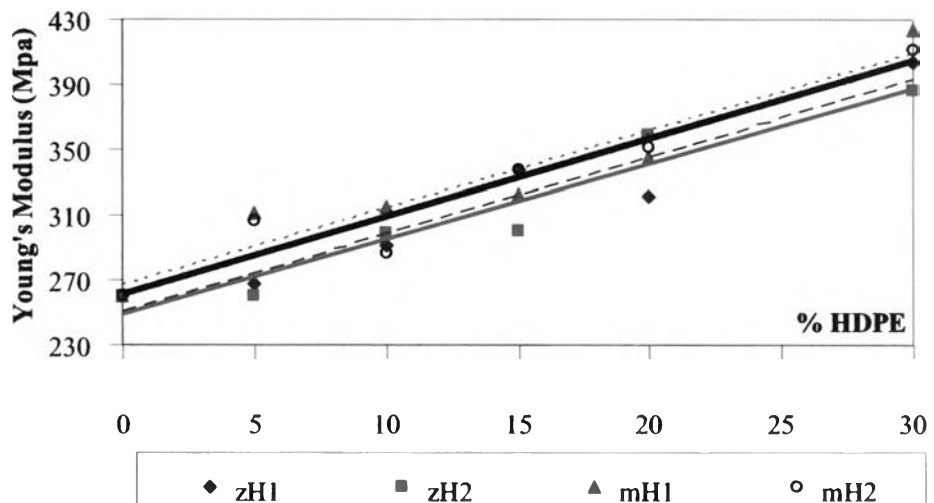


Figure 4.2 : Effect of HDPE content on Young's modulus in transverse direction of LLDPE/LDPE/HDPE blown films.

4.1.1.2 Effect of HDPE content on tensile strength

Polymer molecules tend to align themselves along the flow field; therefore, in the blown-film extrusion process, the polymer molecules are likely to orient along both the machine and the transverse directions. Due to the very high crystallizability and the low melt strength, free-form extrusion of HDPE was somewhat difficult as distortion of the extrudate is rather common. In order to obtain a good orientation of HDPE along the transverse direction of the blown film, a high blow-up ratio around 3 to 5:1 is required. However, the blown-film extrusion line used in this particular work was configured for LLDPE and LDPE, so achievable blow-up ratio was only 1.78:1.

Figures 4.3 and 4.4 showed the tensile strength of LLDPE/LDPE/HDPE blown films tested along both the machine and the transverse directions. For a given blend system, the tensile strength of the films in the machine direction was found to increase, while that of the films in the transverse direction was found to decrease, with increasing HDPE content. With increasing HDPE content, the mobility of the matrix molecules became more restricted due to the increase in the crystallizability of the matrix. This caused the orientation of the matrix molecules in the transverse direction became more difficult as the content of HDPE in the blends increased. In addition, the blown films from the blends containing m-LLDPE exhibited much greater tensile strength than those from the blends containing zn-LLDPE. The explanation for such an observation is similar to that given in the previous subsection.

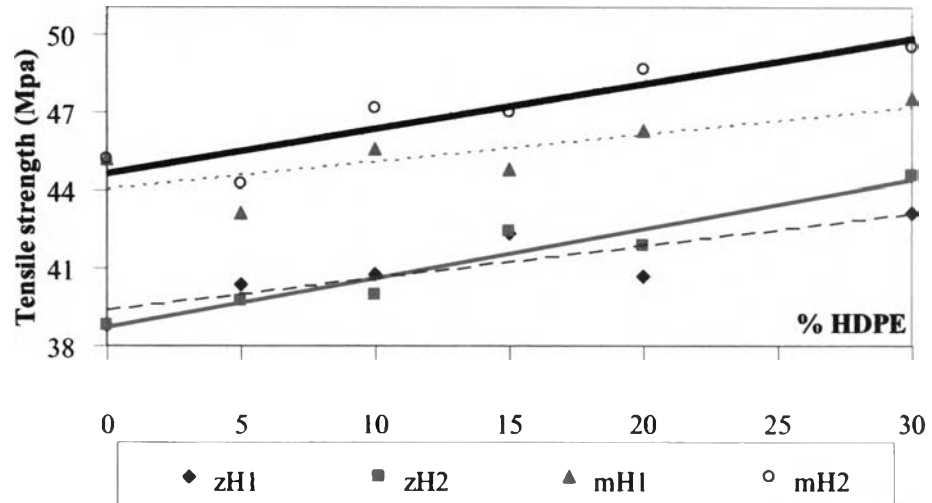


Figure 4.3 : Effect of HDPE content on tensile strength in machine direction of LLDPE/LDPE/HDPE blown film.

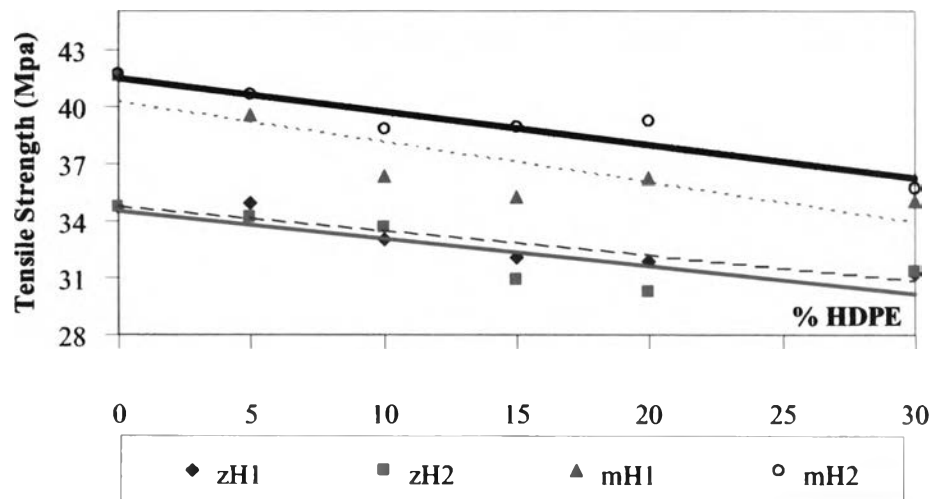


Figure 4.4 : Effect of HDPE content on tensile strength in transverse direction of LLDPE/LDPE/HDPE blown film.

The result in transverse direction was in contrast to that reported by Hatairat [6] on blown films from HDPE and LLDPE blends (0-40% LLDPE) and by Nuchanan [7] on those from HDPE and LLDPE (0-40% HDPE) in which they found that the tensile strength of HDPE/LLDPE blown films decreased with increasing LLDPE content. In

other words, when HDPE content increased, the tensile strength of HDPE/LLDPE blown films increased. However, no clear information with regards to the blow-up ratio used or the die diameter or lay flat width was given that could be used as a reference to this work.

In addition, another reason for the observed lower tensile strength of the films from the blends containing zn-LLDPE in comparison with those from the blends containing m-LLDPE could be due to the difference in the crystallization ability of zn-LLDPE in comparison with that of m-LLDPE. H. Lee et al. [21] showed that the apparent melting temperature increased when the lamellar thickness increased. Since it was shown in the literature that m-LLDPE had apparent melting point greater than that of zn-LLDPE [24,25], the lamellar thickness of m-LLDPE should be larger than that of zn-LLDPE. The m-LLDPE had more uniform distribution of short chain branching along its molecules, as described in Section 4.1.1.1, therefore the blown films from the blends containing m-LLDPE should be responsible for the observed greater tensile strength in comparison with the blown films from the blends containing zn-LLDPE.

High tensile strength is important for flexible packaging especially heavy duty category, m-LLDPE/LDPE/HDPE for both HDPE1 and HDPE2 which showed high tensile strength, is suitable for heavy duty film protection.

4.1.1.3 Effect of HDPE content on elongation at break

Figures 4.5 and 4.6 showed elongation at break of LLDPE/LDPE/HDPE blown films in both the machine and the transverse directions as measured by universal testing machine. The elongation at break of LLDPE/LDPE/HDPE blown films decreased with increasing HDPE content in both directions.

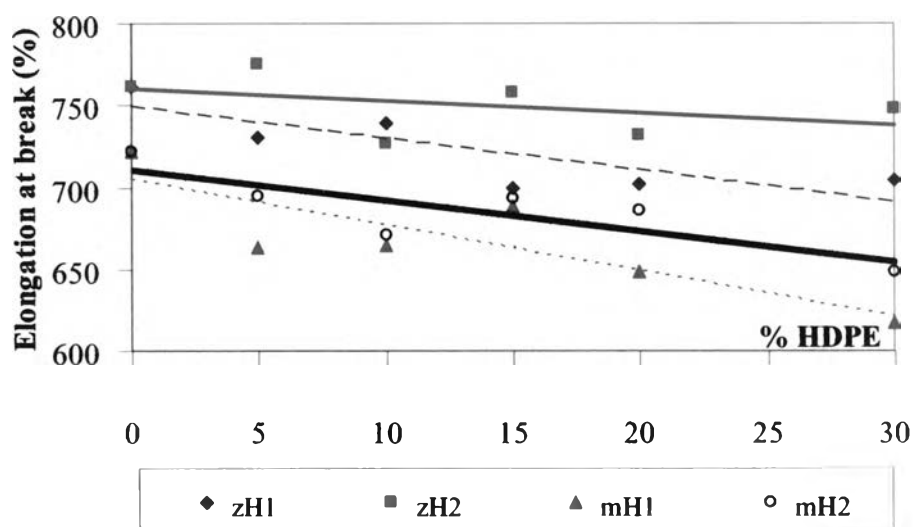


Figure 4.5 : Effect of HDPE content on elongation at break in machine direction of LLDPE/LDPE/HDPE blown film.

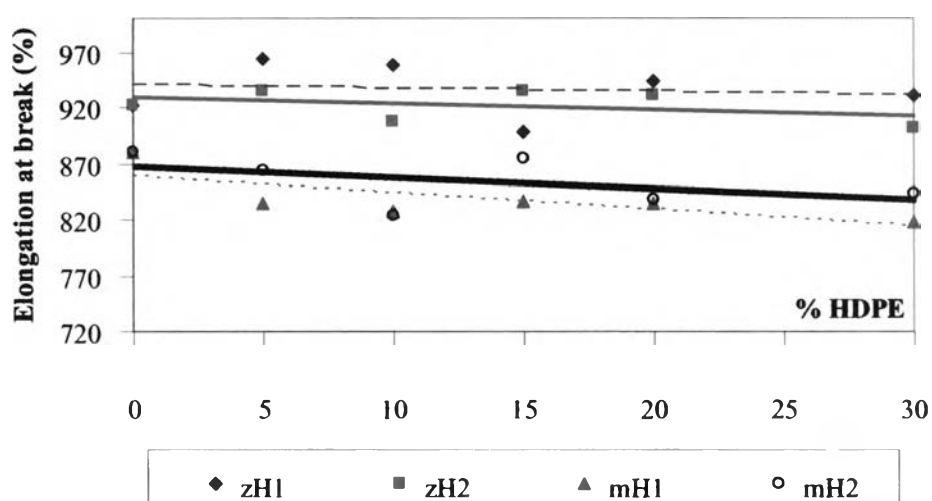


Figure 4.6 : Effect of HDPE content on elongation at break in transverse direction of LLDPE/LDPE/HDPE blown film.

Similar results were reported by Hatairat [6] and Nuchanan [7]. They found that the elongation at break of the HDPE/LLDPE blown films increased with increasing LLDPE content in the HDPE/LLDPE blown films. In other words, when HDPE content increased, the elongation at break of HDPE/LLDPE blown films decreased.

The elongation at break depended on the amorphous phase that was present in the blown films. With increasing HDPE content, the amorphous content in the films was found to decrease. Decreasing the amorphous content in the films caused the films to be less deformable. Due to lower amorphous phase of HDPE comparing to LLDPE and LDPE, the higher HDPE content in the blown films would lead to lower free volume. The LLDPE, which has greater extensibility than does HDPE, contributes very little to the increase in the elongation at break of the blown films. Entrapment of molecular segments in cocrystallites leaves quite small lengths of LLDPE segments in the amorphous region, which might account for the low elongation at break of the blown films. This indicates that breaking occurs before LLDPE content contributes to the elongation of the sample beyond the limit of maximum elongation of HDPE [15].

Furthermore, it was found that at the same resin proportion, the elongation at break of m-LLDPE/LDPE/HDPE blown films was lower than that of zn-LLDPE/LDPE/HDPE blown films in both directions. Since the m-LLDPE had higher crystallinity than zn-LLDPE, as described in Section 4.1.2.1, the films containing m-LLDPE would have a lower amorphous phase and thus lower elongation at break. However, this low elongation at break is suitable for some applications, e.g., 5 kg packaging bag for rice. In this case, the blown film of m-LLDPE/LDPE/HDPE is appropriate for this the requirement.

4.1.1.4 Effect of HDPE content on Elmendorf tear

In the film blowing process, the orientation occurs in the melt state as a result of the shear stress induced by the nip rolls and the pressurized air. Polyethylene films generally show crystalline lamellae aligned perpendicular to machine direction and the lamellae can be twisted or non-twisted [3] depending on the type of polyethylene and the blow up ratio. In this study, such behavior of the blown film had been investigated by measuring the Elmendorf tear.

The results of Elmendorf tear measurement are depicted in Figures 4.7 and 4.8. It can be seen that the increase in the HDPE content decreases the tear resistance of the blown films in the machine direction, while it increases the tear resistance of the blown films in the transverse direction.

Generally, the blow up ratio for HDPE blown film is 3 to 5:1, while the blow-up ratio of the ternary blend blown film obtained from the used machine is up to 1.78 : 1. This would affect the Elmendorf tear in the machine direction to decrease with increasing HDPE content. Morphologies and orientation of the blown film at blow-up ratio 2:1 for HDPE, LLDPE and LDPE had been studied by X.M. Zhang et al. [3]. The HDPE crystalline morphology, which has a column-like morphology and lamellar orientations are perpendicular to the machine direction and non-twisted. Although LLDPE differs from HDPE, the LLDPE morphologies presented display spherulite-like superstructure and relatively random lamellar arrangements. The separated column-like morphology of HDPE obviously caused the LLDPE/LDPE/HDPE blown films to exhibit a low Elmendorf tear resistance in the machine direction and a high Elmendorf tear in the transverse direction.

The tear resistance is an important property of heavy duty film application as well as tensile strength. Considering the tear resistance in both directions, m-LLDPE/LDPE/HDPE2 blown films tend to be better than the other blown films because of their higher Elmendorf tear in both directions.

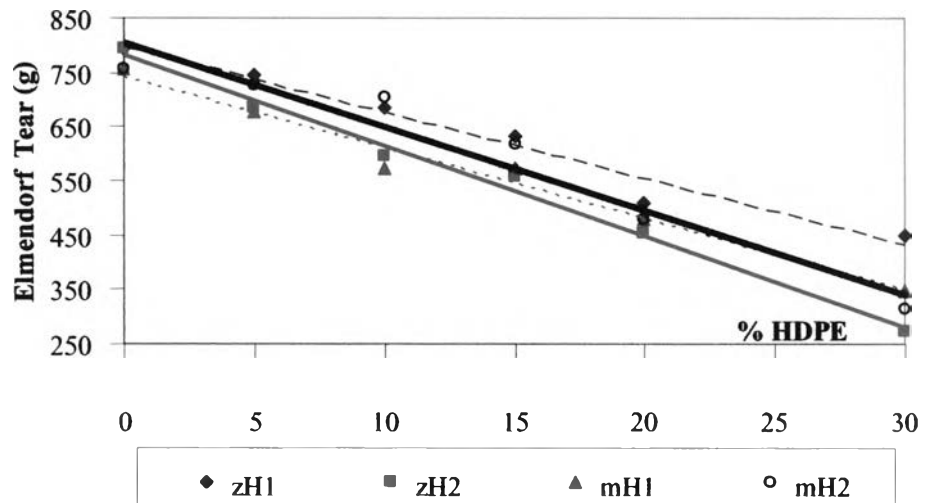


Figure 4.7 : Effect of HDPE content on Elmendorf tear in machine direction of LLDPE/LDPE/HDPE blown film.

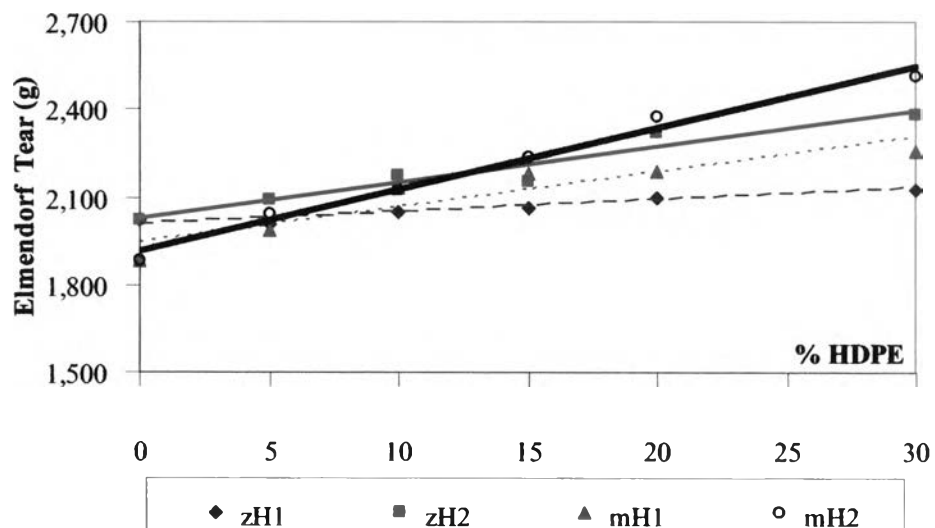


Figure 4.8 : Effect of HDPE content on Elmendorf tear in transverse direction of LLDPE/LDPE/HDPE blown film.

4.1.1.5 Effect of HDPE content on dart impact resistance

Figure 4.9 give the dart impact resistance of LLDPE/LDPE/HDPE blown films as measured by dart impact tester. The dart impact resistance decreases when the HDPE content increases. As HDPE has high crystallinity while LLDPE are more amorphous, the higher HDPE content in the blown film, the higher crystallinity, and thus the impact resistance decreases. Similar observation was reported by Nuchanan [7]. She found that impact resistance of HDPE/LLDPE blown films increased when LLDPE content in HDPE/LLDPE blown films increased. In other words, when HDPE content increased, the impact resistance of HDPE/LLDPE blown film was lower.

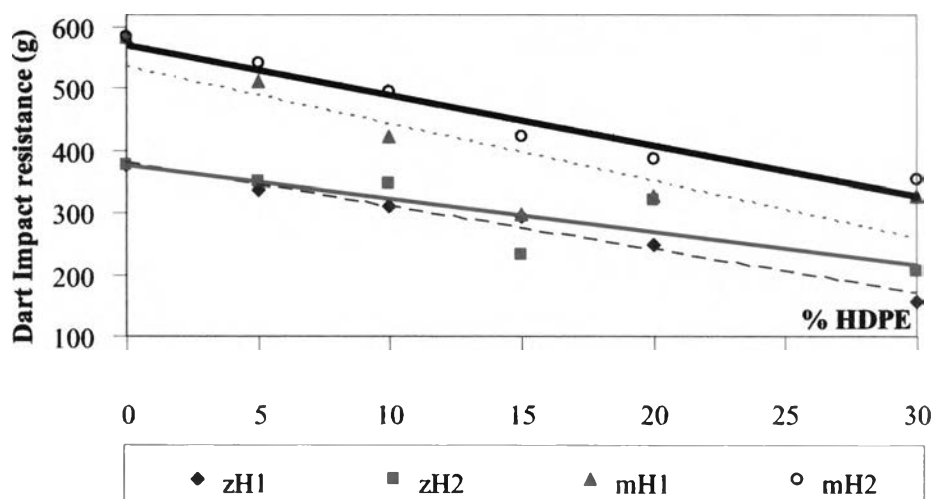


Figure 4.9 : Effect of HDPE content on dart impact resistance of LLDPE/LDPE/HDPE blown film.

Furthermore, in Figures 4.9, comparison of m-LLDPE and zn-LLDPE in the LLDPE/LDPE/HDPE blown films shows that the m-LLDPE had higher dart drop impact resistance than the zn-LLDPE. A similar observation was reported by Majumdar and Kale [19]. They found that impact resistance of LDPE/LLDPE blown films increased when zn-LLDPE was replaced by m-LLDPE. Since m-LLDPE has narrow molecular weight and two to three times smaller size of lamella than zn-LLDPE, the

easier alignment of lamella, then m-LLDPE/LDPE/HDPE blown films should have higher impact resistance than zn-LLDPE/LDPE/HDPE blown films.

Impact resistance is also important for packaging, especially heavy duty film. Since packaging, type heavy duty film require strong packing and handling, m-LLDPE/LDPE/HDPE has advantage which meets high impact resistance.

4.1.1.6 Effect of HDPE content on puncture resistance

Figures 4.10 showed the puncture resistance of LLDPE/LDPE/HDPE blown films as measured by universal testing machine. It can be seen that the increase of HDPE content in blown films shows little difference.

Furthermore, in Figures 4.10, comparison of m-LLDPE and zn-LLDPE in the LLDPE/LDPE/HDPE blown films shows that the m-LLDPE had higher puncture resistance than the zn-LLDPE. The blown films from the blends containing m-LLDPE has advantage for packaging, especially high puncture resistance.

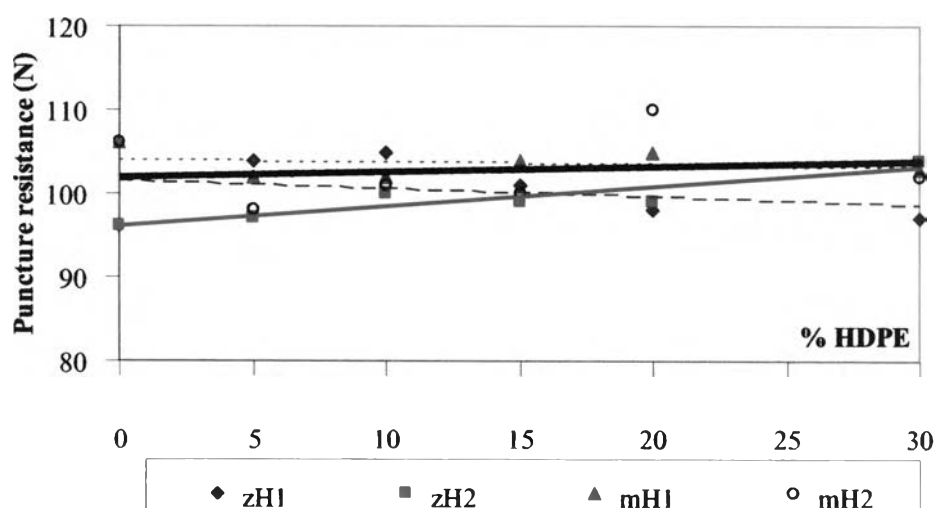


Figure 4.10 : Effect of HDPE content on puncture resistance of LLDPE/LDPE/HDPE blown film.

4.1.2 Effect of HDPE content on physical properties of LLDPE/LDPE/HDPE blown film

4.1.2.1 Effect of HDPE content on haze

Generally, the higher crystallinity in the blown film causes less transmission of light through the film, i.e., higher haze property.

The results of haze of LLDPE/LDPE/HDPE blown films are shown in Figures 4.11 as measured by haze measuring machine. It can be seen that the increase of HDPE content in blown films gives higher haze, due to the increase in the crystallinity of the blown films with increasing HDPE content (see Section 4.3).

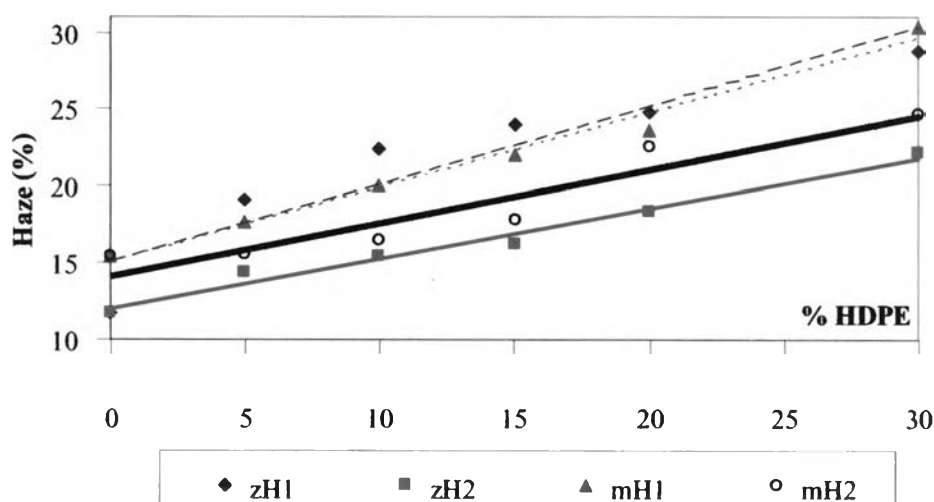


Figure 4.11 : Effect of HDPE content on haze of LLDPE/LDPE/HDPE blown film.

Blown films of LLDPE/LDPE/HDPE containing HDPE2 for both m-LLDPE and zn-LLDPE exhibited haze lower than the blown films containing HDPE1. The blown films of zn-LLDPE/LDPE/HDPE2 had lower haze than m-LLDPE/LDPE/HDPE2. Since the extent of quenching for m-LLDPE/LDPE/HDPE blown film was lower than that for

zn-LLDPE/LDPE/HDPE blown film, the lower extent of quenching allows crystals to grow much better, hence the observed higher crystallinity [20].

Some packaging film requires less haze, i.e., optical transparency. This allows the customers to appreciate visual observation of the products inside. Based on this, blown films of zn-LLDPE/LDPE/HDPE2 exhibited much better optical transparency than those of m-LLDPE/LDPE/HDPE2.

4.1.2.2 Effect of HDPE content on gloss

Gloss is necessary for packaging since gloss makes packaging more beautiful. Figure 4.12 shows the gloss of LLDPE/LDPE/HDPE blown films as measured by gloss measuring machine. As can be seen, an increase in the HDPE content in blown films makes the gloss of blown films decreased.

In principle, polymers crystal dominates the reflection and transmission of light passing through the films. If small crystal structure exists, the best gloss can be obtained. Factors properties dominating are low density (low crystal quantity), high melt flow index (small crystal size) or molecular weight distribution (uniform crystal size).

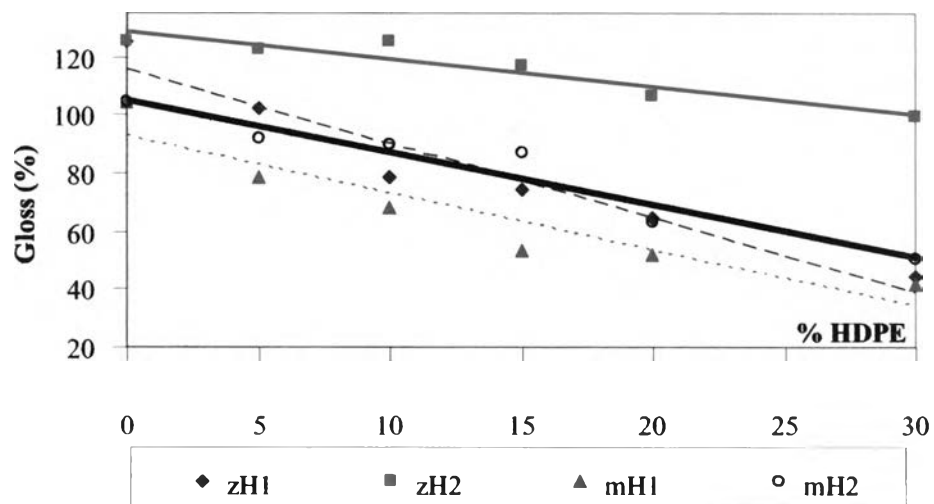


Figure 4.12 : Effect of HDPE content on gloss of LLDPE/LDPE/HDPE blown film.

The blown films containing zn-LLDPE and HDPE2 exhibit the best gloss property, while those containing m-LLDPE and HDPE1 were the worst. Based on the results obtained, the blown films containing HDPE2 exhibited much better gloss than those containing HDPE1, while the blown films containing zn-LLDPE exhibited much better gloss than those containing m-LLDPE. A similar explanation based on the crystallinity content within the films could be used here.

4.1.2.3 Effect of HDPE content on gel content

Gel formation of film was caused by several types, e.g. contamination from dirt, unmelted of polymer, polymer degradation and immisibility of polymer blend [23]. Gel count cannot be done on LLDPE/LDPE/HDPE1 blown film because of its rough surface. Table 4.1 shows the content of gels of varying size range, i.e., greater than 1.5 mm, 0.8 – 1.5 mm and 0.4 – 0.8 mm, respectively, on an observed area of 1 m². It can be seen no significant difference in the gel content was observed with variation in the HDPE content, but the films containing zn-LLDPE had much greater gels than those containing m-LLDPE. Since the m-LLDPE had narrow molecular weight and a more homogenous short chain branching distribution leads to difficult to crosslinking of polymer. As a results, low gel was appeared in the ternary blend blown film with m-LLDPE.

Even though gel is a problem for printing and appearance of packaging but the amount of gel particles observed here was acceptable by the industrial standards.

Table 4.1 Effect of HDPE content on gel count of LLDPE/LDPE/HDPE blown film.

Gel diameter Formula	Gel count		
	> 1.5 mm	0.8 – 1.5 mm	0.4 – 0.8 mm
zH000	1	0	6
mH000	0	1	2
zH205	0	0	3
zH210	0	1	3
zH215	2	0	7
zH220	0	0	2
zH230	0	0	6
mH205	0	1	0
mH210	1	1	0
mH215	0	0	2
mH220	0	0	1
mH230	0	1	6

4.1.2.4 Effect of HDPE content on throughput

This throughput of blown films was carried out by measuring the weight of the film that was extruded in 5 min. Table 4.2 shows throughput of LLDPE/LDPE/HDPE blown films. It can be seen that m-LLDPE/LDPE/HDPE blown film throughput is lower than m-LLDPE/LDPE/HDPE blown film. This is due to the lower melt flow index of m-LLDPE in comparison with that of zn-LLDPE. The zH130 blend was not listed in Table 4.2 because when the particular blend was extruded at a screw speed of 35 rpm, stable bubble could not be form: the screw speed had to be reduced to 27 rpm. It should be noted that the die temperature was fixed at 200 °C.

Table 4.2 Effect of HDPE content on throughput of LLDPE/LDPE/HDPE blown film.

Formula	Throughput (Kg./ 5 minutes)	Formula	Throughput (Kg./ 5 minutes)
zH000	2.15	mH000	1.93
zH105	2.16	mH105	1.94
zH110	2.15	mH110	1.91
zH115	2.13	mH115	1.93
zH120	2.14	mH120	1.89
zH130	-	mH130	1.88
zH205	2.15	mH205	1.95
zH210	2.18	mH210	1.95
zH215	2.16	mH215	1.94
zH220	2.17	mH220	1.94
zH230	2.16	mH230	1.91

In addition, Table 4.2 showed throughput decreased with increasing HDPE content in the blown films. Also, the blown film containing zn-LLDPE and HDPE2 had slightly more throughput than containing zn-LLDPE and HDPE1, as same as the blown film containing m-LLDPE and HDPE2 which has more throughput than containing m-LLDPE and HDPE1. All those were the result of having melt flow index of HDPE2 higher than that of HDPE1.

4.1.2.5 Effect of HDPE content on initial seal temperature

Figures 4.13 and 4.14 showed the initial seal temperature at load 3 Newton of LLDPE/LDPE/HDPE blown films, especially HDPE2, LLDPE/LDPE/HDPE1 blown films not tested because of its rough surface cannot be sealed. The test method is sealing by seal temperature machine and test seal strength by universal testing machine. It can be seen that increasing HDPE content increased the initial seal temperature. The blown film without HDPE content and that containing 5% HDPE, both with zn-LLDPE and m-LLDPE, have the lowest initial seal temperature around 120.6 °C. The initial seal temperature of the blown films both containing zn-LLDPE and m-LLDPE was found to be the highest around 135.0 – 135.6 °C at the highest HDPE content investigated (i.e., 30%). This is due to the increase in the crystallinity of the films with increasing HDPE and the higher apparent melting of HDPE.

Low initial seal temperature is important for an automatic packaging, leading to decreased sealing time (faster sealing) or decreased sealing temperature (same sealing time, but less utilization of energy).

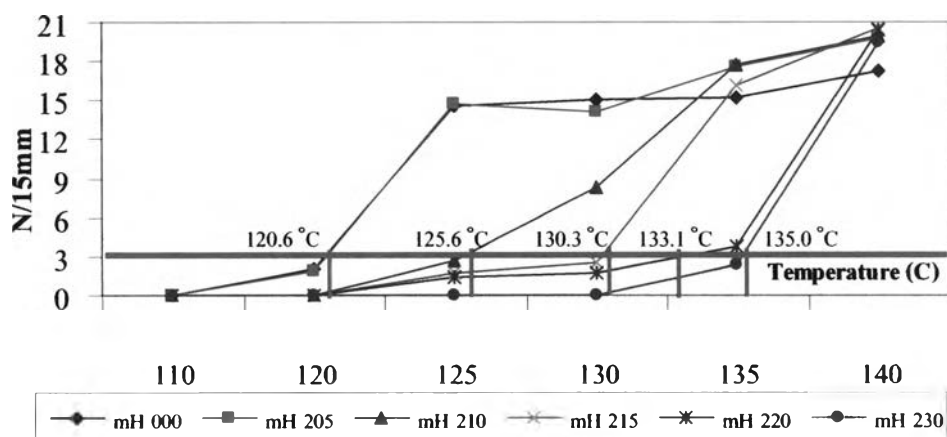


Figure 4.13 : Effect of HDPE content on initial seal temperature of m-LLDPE/LDPE/HDPE blown film.

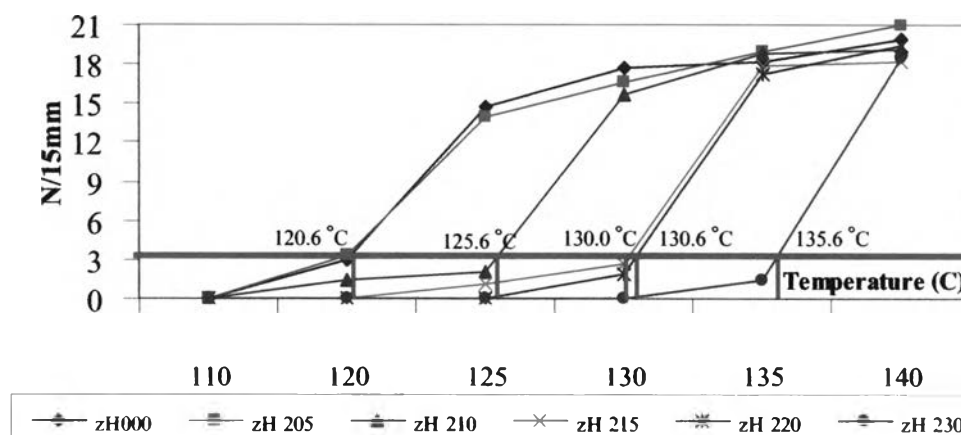


Figure 4.14 : Effect of HDPE content on initial seal temperature of zn-LLDPE/LDPE/HDPE blown film.

4.2 Effect of LDPE content

When considering the appearance of LLDPE/LDPE/HDPE1 blown films, the films that contained both zn-LLDPE and m-LLDPE showed rough surface. The reason could be the much difference in the melt flow indices among the various components in the blends. The actual use for the LLDPE/LDPE/HDPE1 blown films cannot therefore be realized in practice. On the other hand, LLDPE/LDPE/HDPE2 blown films is not different from the blown film without HDPE (LLDPE/LDPE blown film). As shown previously, increasing HDPE content caused the films to be stiffer and less optically clear.

In this part, HDPE content in ternary blend blown films was kept constant at 15% because mechanical and physical properties show an intermediate value between HDPE content 5-30%, while the LDPE content was varied (i.e., 5, 15, and 25%).

4.2.1 Effect of LDPE content on mechanical properties of LLDPE/LDPE/HDPE blown film

4.2.1.1 Effect of LDPE content on Young's modulus

Young's modulus of LLDPE/LDPE/HDPE blown films in both the machine and the transverse directions for various LDPE content including that for the films without the addition of HDPE is summarized in Figures 4.15 and 4.16, respectively.

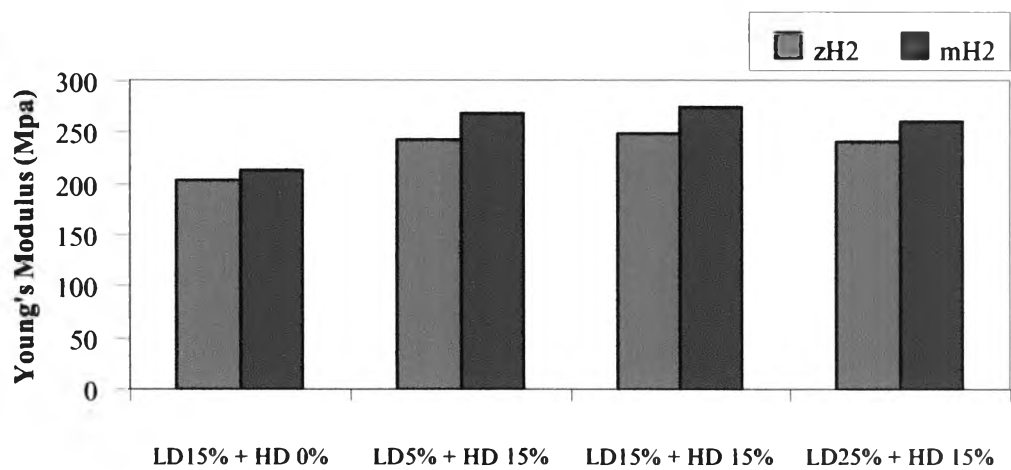


Figure 4.15 : Effect of LDPE content on Young's modulus in machine direction of LLDPE/LDPE/HDPE blown film.

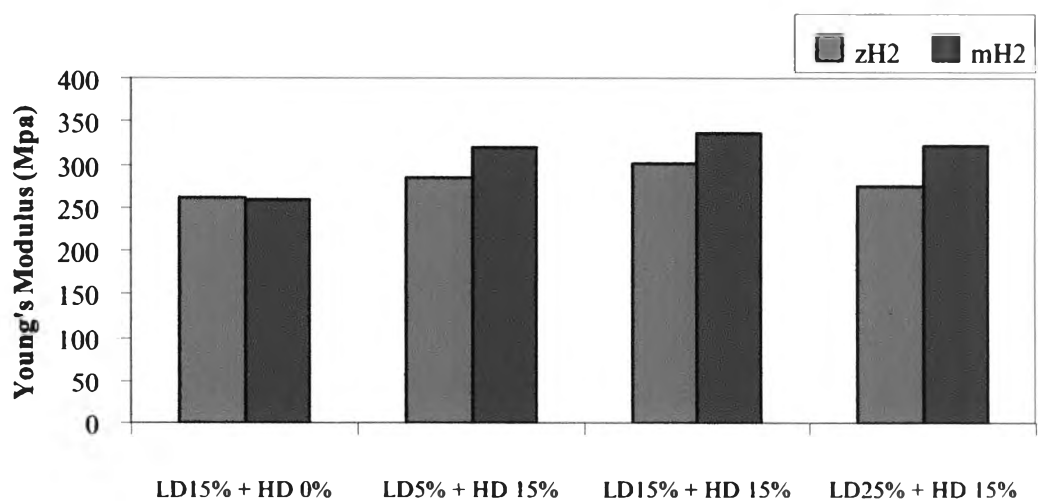


Figure 4.16 : Effect of LDPE content on Young's modulus in transverse direction of LLDPE/LDPE/HDPE blown film.

All of the blown films containing 15% HDPE exhibited greater Young's modulus than those without HDPE. It is because of the influence of HDPE as described in Section 4.1.1.1. The blown film containing 15% LDPE exhibited the highest Young's modulus in both the machine and the transverse directions, which did not differ much from the films containing 5% and 25% LDPE. However, the blown film containing 25% LDPE showed a lower Young's modulus due to the increase in the amorphous content as a result of the high LDPE content.

Furthermore, according to Figures 4.15 and 4.16, the blown films containing m-LLDPE exhibited higher Young's modulus than those containing zn-LLDPE in both directions. A similar result was described in Section 4.1.1.1 which is due to the fact that m-LLDPE had a higher molecular weight, narrow molecular weight and a more homogenous short chain branching distribution that lead faster response to an external stress.

The stiffness of film for automatic packing is the most important requirement, as described in Section 4.1.1.1. Then, m-LLDPE/LDPE/HDPE blown films containing 5% and 15% LDPE are appropriate for film automatic packing.

4.2.1.2 Effect of LDPE content on tensile strength

Figures 4.17 and 4.18 showed tensile strength of LLDPE/LDPE/HDPE blown films in both machine and transverse directions in comparison with that without HDPE as measured by universal testing machine. It can be seen that an increase in the LDPE content tends to decrease the tensile strength of the blown films in both directions. The LDPE are known to has more amorphous phase than LLDPE, arising from long-chain branching in LDPE. In other words LDPE has low crystallinity than LLDPE, so when LDPE content in the blown film increases, its long-chain branching will disturb the

orientation of the molecule in the blend. Consequently, the tensile strength of the film was found to decrease. In the machine direction, the tensile strength of the blown film without HDPE was lower than that of the blown film containing 5% and 15% LDPE. However, it had tensile strength higher than the blown film containing 25% LDPE. In the transverse direction, the tensile strength of the blown film without HDPE was greater than that of the blown films at all composition of LDPE.

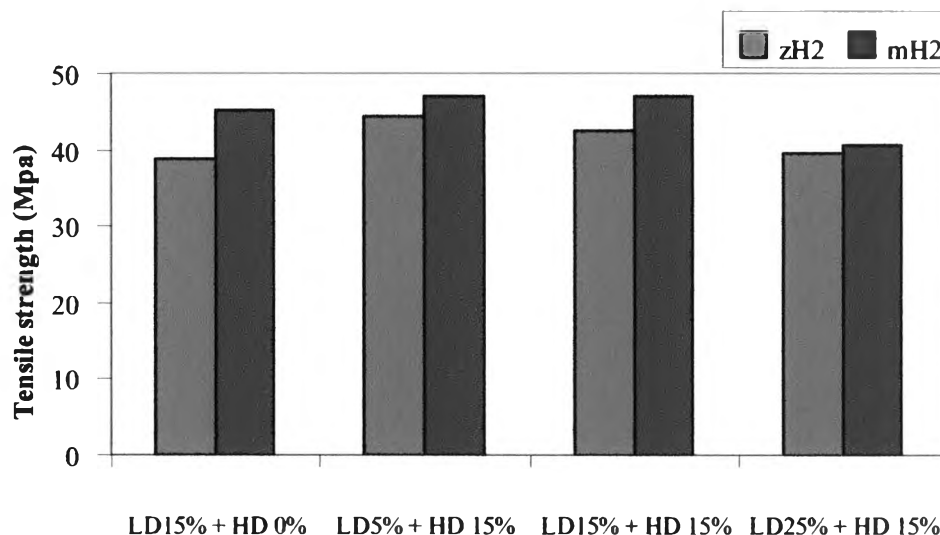


Figure 4.17 : Effect of LDPE content on tensile strength in machine direction of LLDPE/LDPE/HDPE blown film.

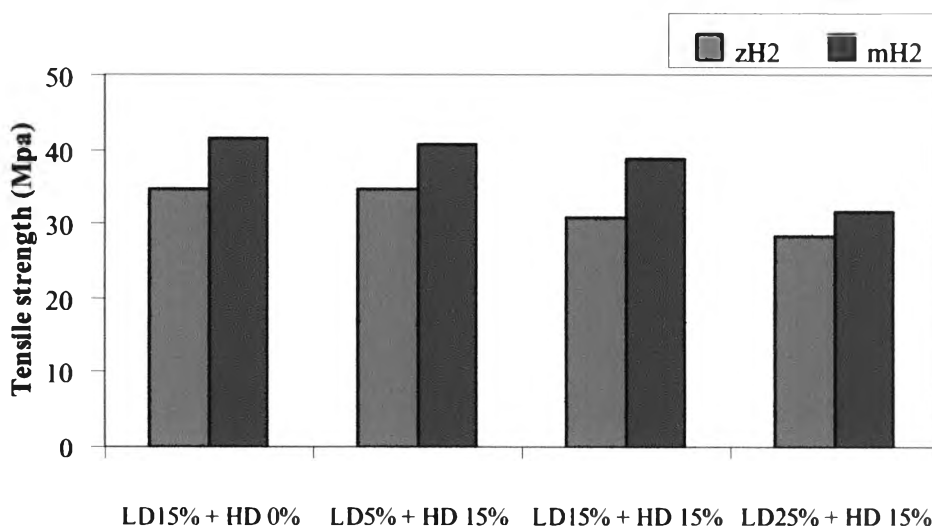


Figure 4.18 : Effect of LDPE content on tensile strength in transverse direction of LLDPE/LDPE/HDPE blown film.

The similar result was described in Section 4.1.1.2 in which the tensile strength of the blown films containing m-LLDPE was higher than those containing zn-LLDPE. Therefore, m-LLDPE/LDPE/HDPE blown films containing 5% and 15% LDPE are appropriate for heavy duty packaging.

4.2.1.3 Effect of LDPE on elongation at break

Elongation at break of LLDPE/LDPE/HDPE blown films in both machine and transverse directions for all LDPE contents is shown in Figures 4.19 and 4.20 in comparison with the blown film without HDPE as measured by universal testing machine.

In the machine direction, the blown film without HDPE was higher than the blown films for all of the LDPE contents. It can also be seen that the elongation at break decreased with increasing LDPE content. In the transverse direction, the elongation at break of the blown films containing LDPE content decreased with increasing LDPE content.

As previously mentioned, a high elongation at break is not necessary for heavy duty packaging film. The elongation at break of m-LLDPE/LDPE/HDPE blown films was lower than that of zn-LLDPE/LDPE/HDPE blown films. In this case, the blown film of m-LLDPE/LDPE/HDPE is appropriate for this the requirement.

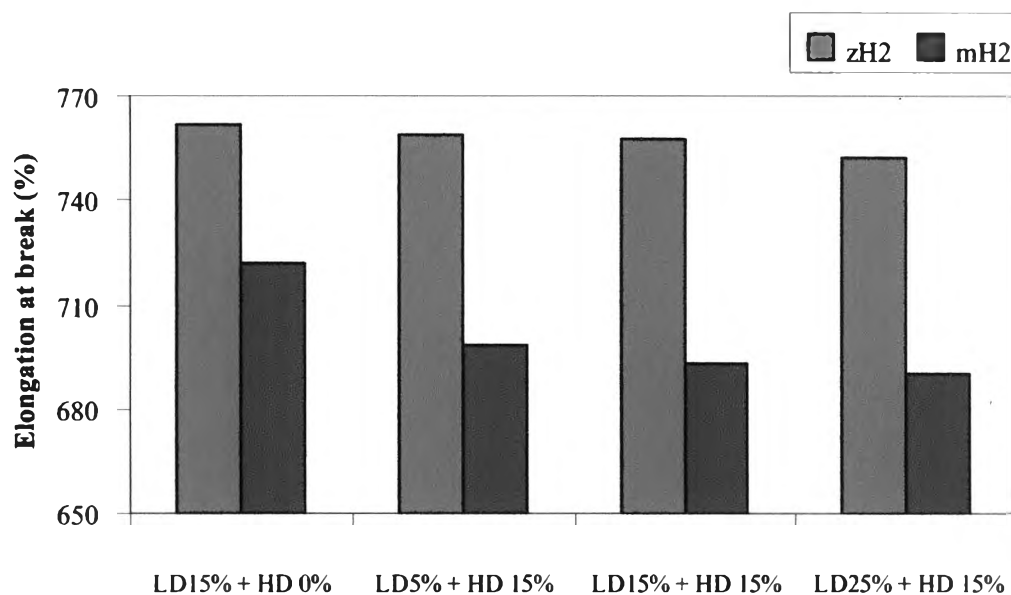


Figure 4.19 : Effect of LDPE content on elongation in machine direction of LLDPE/LDPE/HDPE blown film.

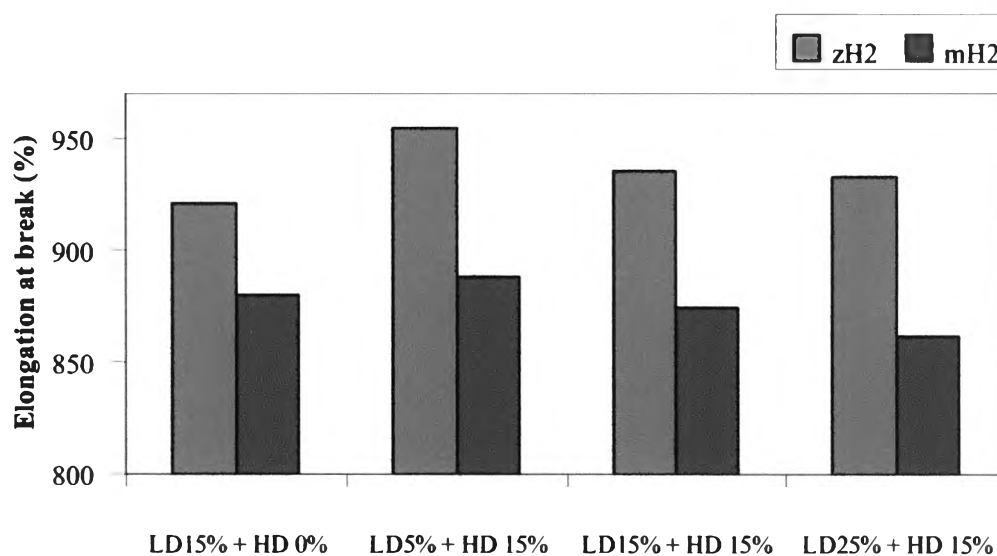


Figure 4.20 : Effect of LDPE content on elongation in transverse direction of LLDPE/LDPE/HDPE blown film.



4.2.1.4 Effect of LDPE content on Elmendorf tear

Figures 4.21 and 4.22 were showed Elmendorf tear of LLDPE/LDPE/HDPE blown film in both the machine and transverse directions, respectively. It can be seen that an increase in the LDPE content decreased the Elmendorf tear resistance of blown film in the machine direction but an opposite result was observed in the transverse direction. The different results of LLDPE/LDPE blown film was reported by U. Yilmazer [17] , in which he found that increasing LLDPE content increased the tear strength of blown film in the transverse direction. In other words, when LLDPE content decreased, tear strength of LLDPE/LDPE blown films decreased. Influence of blow up ratio on the blown film with content HDPE may be reason on this cause.

Similar to Section 4.1.1.4, Elmendorf tear is important for heavy duty packaging film. The blown films of m-LLDPE/LDPE/HDPE had Elmendorf tear greater than that of zn-LLDPE/LDPE/HDPE blown films, therefore m-LLDPE/LDPE/HDPE blown film is appropriate for heavy duty packaging film.

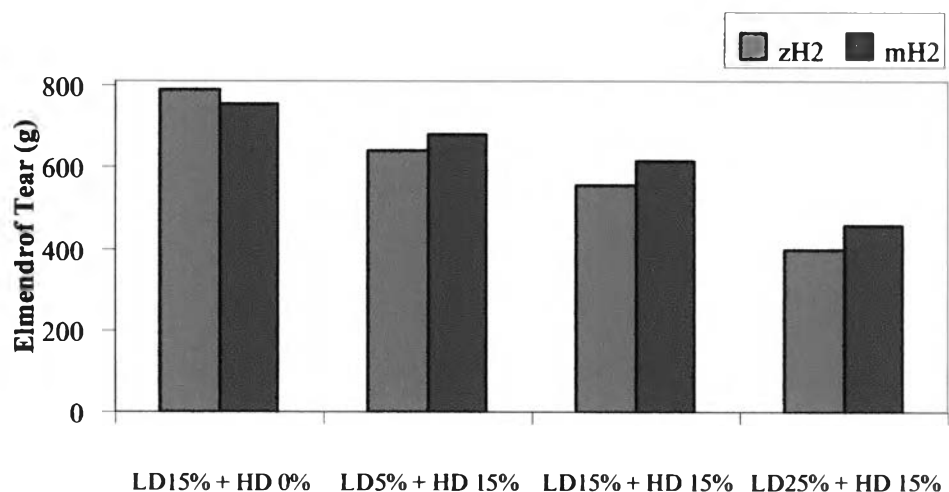


Figure 4.21 : Effect of LDPE content on Elmendorf tear resistance in the machine direction of LLDPE/LDPE/HDPE blown films.

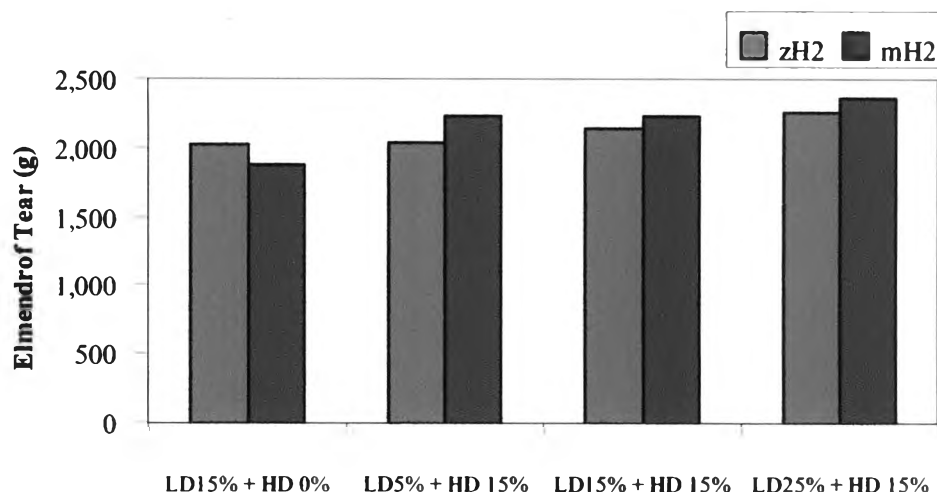


Figure 4.22 : Effect of LDPE content on Elmendorf tear resistance in the transverse direction of LLDPE/LDPE/HDPE blown films.

4.2.1.5 Effect of LDPE content on dart impact resistance

The dart impact resistance of LLDPE/LDPE/HDPE blown films for all LDPE contents in comparison with the film without HDPE as measured by dart impact tester is shown in Figure 4.23. It can be seen that an increase in the LDPE content decreased the dart impact resistance of the blown films. The blown film without HDPE exhibited the property value greater than all of the blown films containing HDPE. The influence of HDPE content in LLDPE/LDPE/HDPE blown film caused the dart impact resistance to be lower the blown film without HDPE, as previously described in Section 4.1.1.5.

Similar to Section 4.1.1.5, the dart impact resistance of the blown films containing m-LLDPE was higher than the blown films containing zn-LLDPE. Therefore, m-LLDPE/LDPE/HDPE blown film was proper for requirement of heavy duty packaging film.

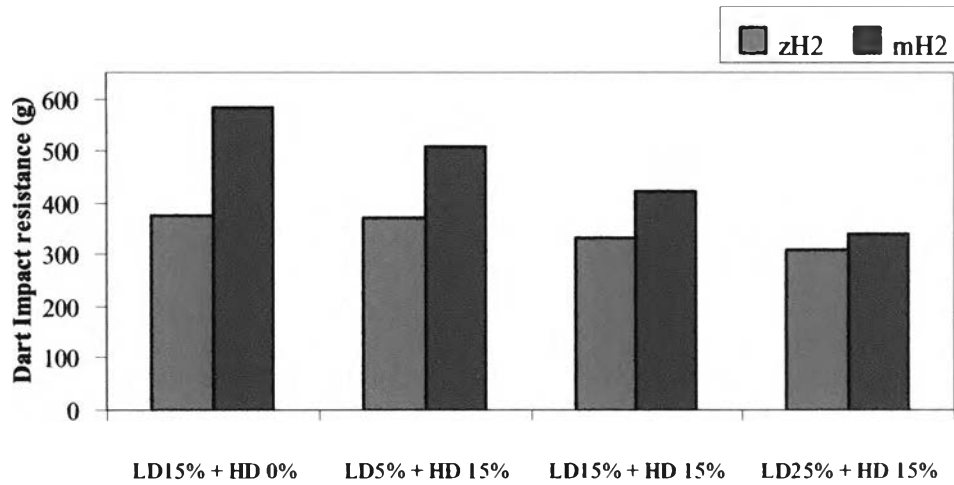


Figure 4.23 : Effect of LDPE content on dart impact resistance of LLDPE/LDPE/HDPE blown film.

4.2.1.6 Effect of LDPE content on puncture resistance

The puncture resistance of LLDPE/LDPE/HDPE blown films for all of LDPE contents in comparison with the film without HDPE as measured by universal testing machine is shown in Figure 4.24. It can be seen that the puncture resistance did not differ not much from the results shown in Section 4.1.1.6.

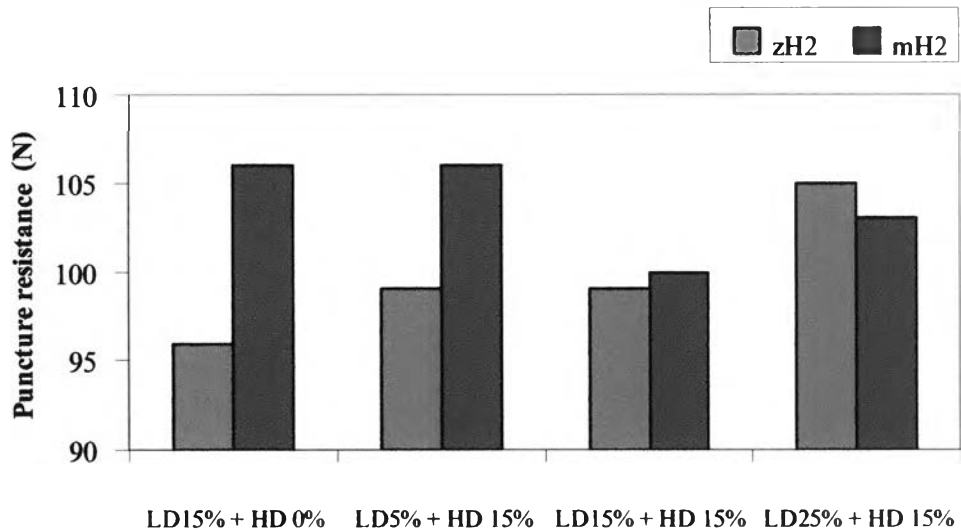


Figure 4.24 : Effect of LDPE content on puncture resistance of LLDPE/LDPE/HDPE blown film.

Furthermore, the puncture resistance of the blown films containing m-LLDPE are higher than that of the blown films containing zn-LLDPE. Therefore, m-LLDPE/LDPE/HDPE blown films are proper for use as packaging film.

4.2.2 Effect of LDPE content on physical properties of LLDPE/LDPE/HDPE blown film

4.2.2.1 Effect of LDPE content on haze

The results of haze of LLDPE/LDPE/HDPE blown films for all of LDPE contents are shown in Figure 4.25 as measured by haze measuring machine. It can be seen that the blown film containing 25% LDPE exhibited the lowest haze property, while such a property for the blown films containing HDPE is greater than the film without HDPE. Similar to Section 4.1.2.1, the HDPE has more crystallinity, comparing to LLDPE and LDPE, therefore the blown films with HDPE had more haze and haze was lower when LDPE content increased.

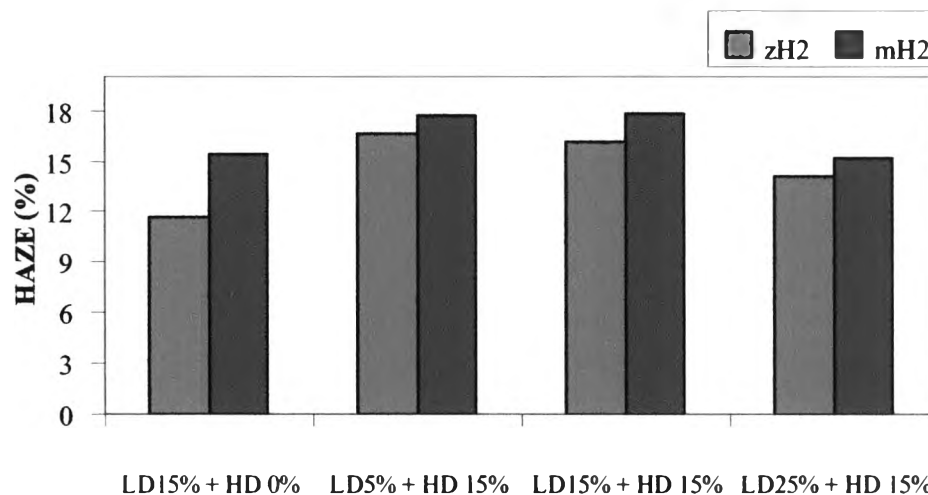


Figure 4.25 : Effect of LDPE content on haze of LLDPE/LDPE/HDPE blown film.

Furthermore, Figures 4.25 shows that the blown films containing zn-LLDPE exhibited low haze than the blown films containing m-LLDPE. Similar to Section 4.1.2.1, less haze or good clarity is important for packaging film, therefore zn-LLDPE/LDPE/HDPE2 film is a better choice than m-LLDPE/LDPE/HDPE2 film due to the better clarity.

4.2.2.2 Effect of LDPE content on gloss

Figure 4.26 shows gloss of LLDPE/LDPE/HDPE blown films in comparison with that without HDPE. For all of the films from ternary blend systems, the variation in the LDPE content did not affect the gloss of the resulting films, regardless of the type of LLDPE used. Interestingly, the blown films without HDPE exhibited greater gloss than that of the films from ternary blends.

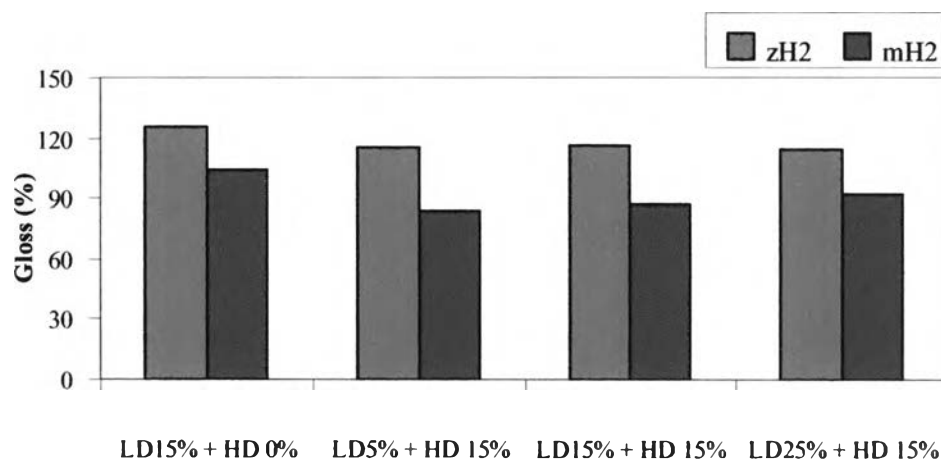


Figure 4.26 : Effect of LDPE content on gloss of LLDPE/LDPE/HDPE blown film.

Similar to Section 4.1.2.2, gloss of the blown films containing zn-LLDPE was greater than that of the films containing m-LLDPE. Gloss is necessary for packaging application since gloss makes packaging more beautiful, therefore zn-LLDPE/LDPE/HDPE blown films are appropriate for packaging applications.

4.2.2.3 Effect of LDPE content on gel content

Table 4.3 shows the number of gel particles on an observing area of 1 m^2 according to the size of the gels (i.e., $>1.5 \text{ mm}$, $0.8 - 1.5 \text{ mm}$ and $0.4 - 0.8 \text{ mm}$) for all of the blown films investigated. It can be seen that the blown films containing zn-LLDPE had greater number of gel particles than those containing m-LLDPE and no variation in the number of gels was observed with the variation in the LDPE content. Similar to what was described in Section 4.1.2.3, that m-LLDPE has narrow molecular weight and a more homogenous short chain branching distribution leads to difficulty in the formation of crosslinking, thus lower gel content for the ternary blends containing m-LLDPE. The number of gels observed in this work is acceptable by the industrial standard.

Table 4.3 Effect of LDPE content on gel count of LLDPE/LDPE/HDPE blown film

Formula \ Gel diameter	Gel count		
	$> 1.5 \text{ mm}$	$> 1.5 \text{ mm}$	$> 1.5 \text{ mm}$
zH000	1	0	6
zH215.05	0	3	7
zH215	2	0	7
zH215.25	0	2	7
mH000	0	1	2
mH215.05	0	0	4
mH215	0	0	2
mH215.25	0	0	2

4.2.2.4 Effect of LDPE content on throughput

Table 4.4 shows throughput of blown films that were measured by weighing the films within 5 min. It can be seen that an increase in the LDPE content caused the mass throughput to decrease. Generally, a material with a high melt flow index should give the product with a high mass throughput. In addition, the films from the ternary blends of zn-LLDPE/LDPE/HDPE exhibited much higher mass throughput than the films from the ternary blends of m-LLDPE/LDPE/HDPE, a direct result of the lower melt flow index of m-LLDPE in comparison with that of zn-LLDPE.

Table 4.4 Effect of HDPE content on throughput of LLDPE/LDPE/HDPE blown film

Formula	Weight per 5 minutes (Kg.)	Formula	Weight per 5 minutes (Kg.)
zH000	2.15	mH000	1.93
zH215.05	2.19	mH215.05	1.99
zH215	2.16	mH215	1.94
zH215.25	2.07	mH215.25	1.93

4.2.2.5 Effect of LDPE content on initial seal temperature

Figures 4.27 to 4.28 give the initial seal temperature at load 3 Newton of the blown film without HDPE and LLDPE/LDPE/HDPE blown films. It can be seen that the blown films containing either m-LLDPE or zn-LLDPE showed the initial seal temperature lower than the blown film without HDPE. The blown films containing 25% LDPE (regardless of the type of LLDPE) exhibited the lowest initial seal temperature around 125.6 °C, while the films containing 5 and 15% LDPE showed the initial seal temperatures between 128 – 130 °C. Similar to what has been given in Section 4.1.2.5, the high crystallinity of HDPE influenced the initial seal temperature of the blown films

and the low crystallinity of LDPE showed the opposite tendency to what was observed for HDPE.

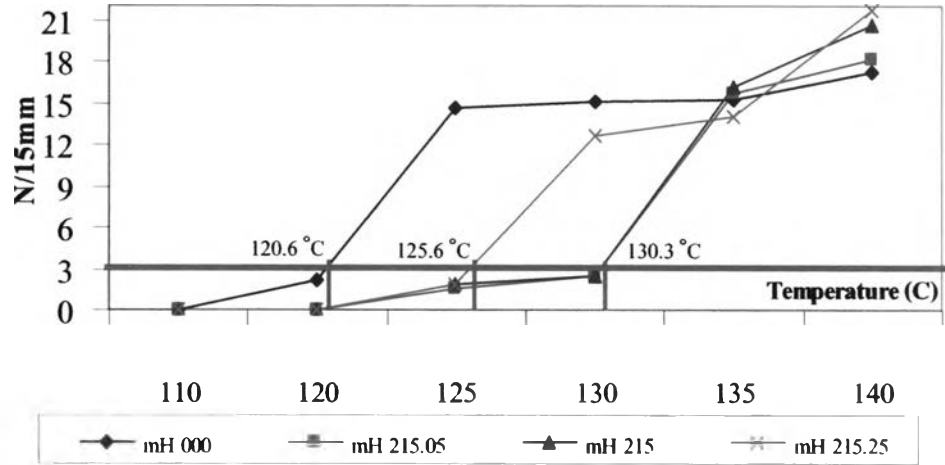


Figure 4.27 : Effect of LDPE content on initial seal temperature of m-LLDPE/LDPE/HDPE blown films.

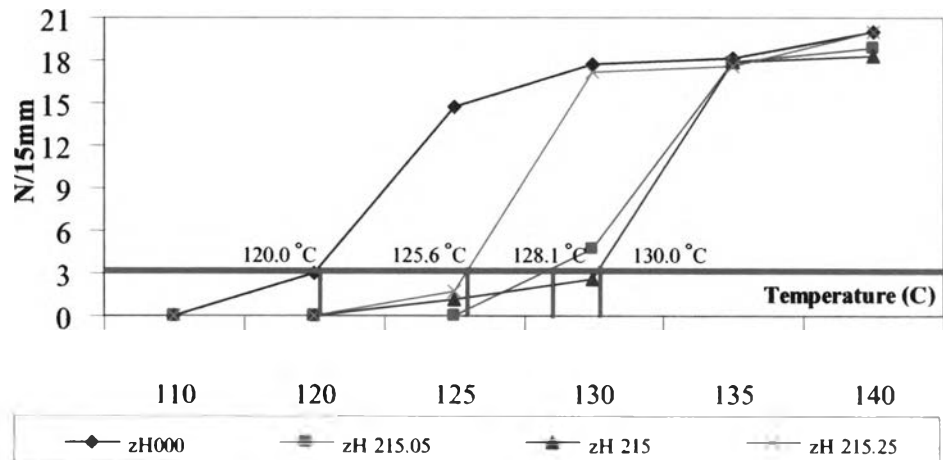


Figure 4.28 : Effect of LDPE content on initial seal temperature of zn-LLDPE/LDPE/HDPE blown films.

4.3 Thermal property of LLDPE/LDPE/HDPE blown film

Figures 4.29 to 4.32 show melting and crystallization curves of LLDPE/LDPE/HDPE blown films as measured by differential scanning calorimetry (DSC). The blown films without HDPE exhibited a single crystallization peak were clearly observed at 108.5 °C for the film containing zn-LLDPE and 109.6 °C for the film containing m-LLDPE. However, the double melting endotherm was observed at 120.2 and 123.0 °C for the film containing zn-LLDPE and at 121.1 and 123.4 °C for the film containing m-LLDPE. The lower melting temperature should correspond to the melting of the LDPE crystals (120.2 and 121.1 °C) and the higher melting temperature should correspond to the melting of the zn-LLDPE (123.0 °C) or m-LLDPE (123.4 °C). This observation could be explained that there are at least two crystalline morphologies existed in the blown film containing zn-LLDPE and m-LLDPE, because two melting peaks were observed even though there is only single crystallization peak.

For the blown films containing HDPE (both HDPE1 and HDPE 2), the non-isothermal melt-crystallization exotherm for each sample was clearly seen to be a single peak which shifted to a higher temperature as the HDPE content increased from 5–30% by weight. Also, the subsequent melting endotherm was observed as a single peak which shifted to the higher temperature as the HDPE content increased. The enthalpy of crystallization (ΔH_c) and the enthalpy of fusion (ΔH_f) were found to increase with increasing HDPE content. The results implied that both the crystallinity (see %crystallinity in Table 4.5) and the lamellar thickness of the films were found to increase with increasing HDPE content.

With regards to the effect of LDPE on thermal behavior of blown films, it was found that both the crystallinity (see % crystallinity in Table 4.5) and the crystallization temperature for both blown films from ternary blends of zn-LLDPE/LDPE/HDPE and

m-LLDPE/LDPE/HDPE was somewhat independent of the LDPE. In other words, the variation of the results obtained was insignificant.

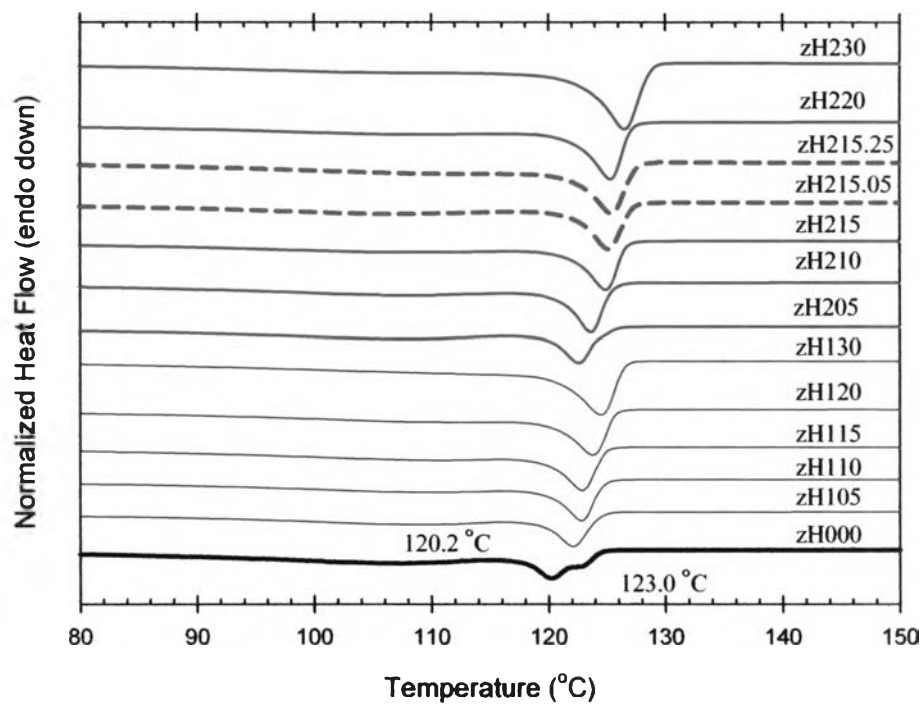


Figure 4.29 : DSC melting curves of zn-LLDPE/LDPE/HDPE blown film.

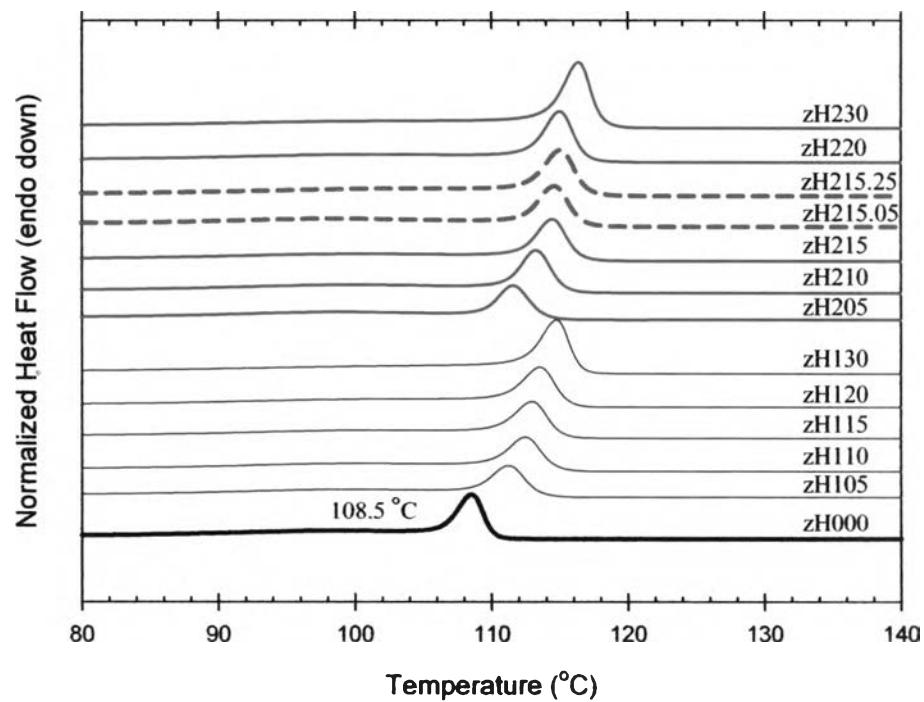


Figure 4.30 : DSC crystallization curves of zn-LLDPE/LDPE/HDPE blown film.

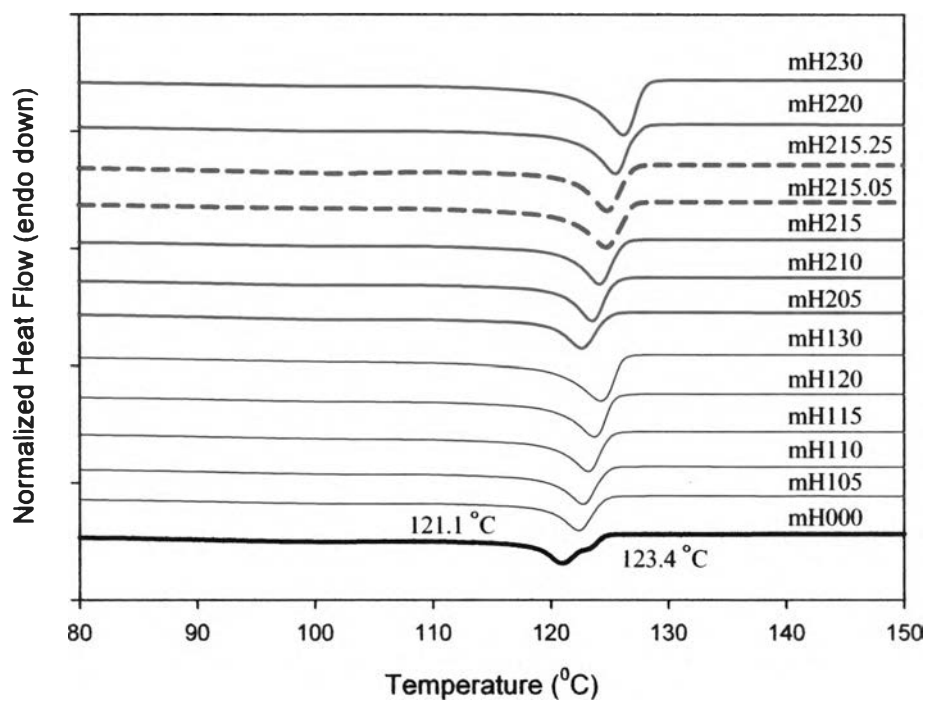


Figure 4.31 : DSC melting curves of m-LLDPE/LDPE/HDPE blown film.

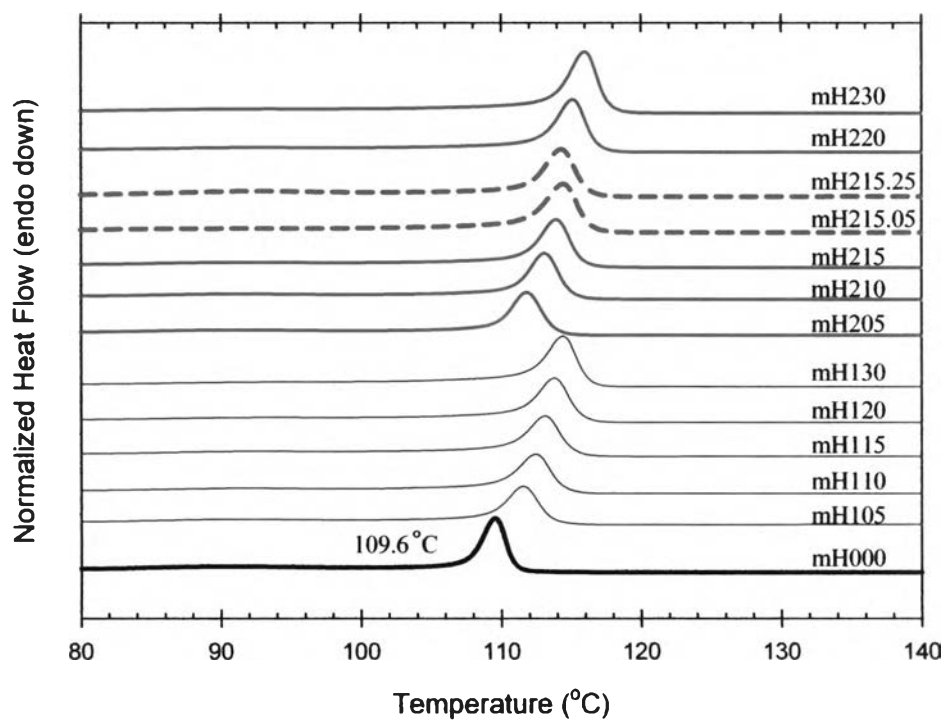


Figure 4.32 : DSC crystallization curves of m-LLDPE/LDPE/HDPE blown film.

Table 4.5 show % crystallinity of LLDPE/LDPE/HDPE blown films were obtained from DSC by the comparison of the heat fusion with a 100% crystalline HDPE heat of fusion of 288 J/g [22] (see equation in Appendix A).

Table 4.5 % Crystallinity of LLDPE/LDPE/HDPE blown film

Formula	% Crystallinity	Formula	% Crystallinity
zH105	29.04	mH105	36.14
zH110	38.15	mH110	39.10
zH115	41.32	mH115	39.01
zH120	42.41	mH120	41.25
zH130	45.14	mH130	43.19
zH205	37.82	mH205	38.81
zH210	43.35	mH210	40.51
zH215	41.84	mH215	40.10
zH215.05	42.87	mH215.05	41.11
zH215.25	44.55	mH215.25	42.37
zH220	43.65	mH220	41.69
zH230	48.63	mH230	44.54