

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Mechanical Properties

HDPE/MLLDPE blends at various contents using MLLDPE produced by three different manufacturers were prepared and their mechanical properties were investigated. These properties included tensile, elongation, flexural modulus, impact strength and heat distortion. Subsequently, the best composition of HDPE/MLLDPE blend was selected; besides, it must be tested by sheet extrusion and vacuum thermoforming processability.

4.1.1 Tensile Strength

Figure 4.1 and Table A-1 show the comparison of the tensile strength of the HDPE/MLLDPE blends at various contents of the three different MLLDPE resins. It can be seen that the increase in MLLDPE content in the three blends decreases the tensile strength of the sheet. The graph shows the tensile strength of blends gradually decreased at 10% to 20% MLLDPE content whereas at 30% to 40% MLLDPE content the tensile strength of blends suddenly decreased. In a separate study by A. K Gupta and et al [14], they reported a similar result of HDPE/LLDPE blend, using conventional LLDPE. However, they observed a decrease as the LLDPE content increased, but at 80% of LLDPE content, the tensile strength dropped. Normally HDPE has a higher tensile strength than LLDPE due to its molecular structure. In sheet processing, the molecule will be oriented in the machine direction because of sheet drawing and pulling by the haul off unit. Therefore, the tensile strength in the machine direction is

higher than in the transverse direction for sheet processes. The explanation for this observation is that the lower orientation stress from the monoaxially orientation in the machine direction causes less orientation of the molecules than in the machine direction. When the MLLDPE content increases, its side chain branching, will disturb the orientation of the molecules in the blend. It is believed that such phenomenon occurred during processing. Consequently, the tensile strength decreases. The sheet extrusion and blown film processes have a similar haul off unit to remove sheet or film from the process by keeping the sheet or film under tension until it is cool enough to remain flat before winding [21]. Accordingly, the organization of the lamella stacks seems to play a critical role on the mechanical properties of the blown film [17], the large lamella is not perfectly aligned or there may not be optimum overlap of one lamella over another when molecules orient during the blowing and pulling in blown film and sheet process.

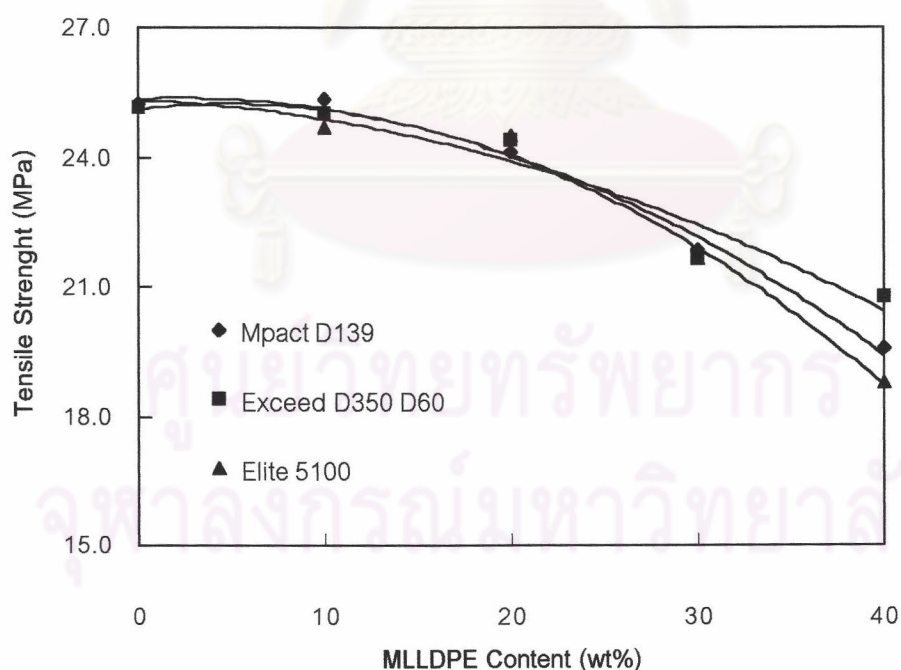


Figure 4.1 Tensile strength of HDPE/MLLDPE blends.

As a result, poor alignment or stacked lamella can reduce the strength of the film or sheet due to weakness in the region between the lamella stacks. Since MLLDPE has the lamella size two or three times smaller than LLDPE, which had better align of the lamella. Consequently, HDPE/MLLDPE sheet was found that tensile strength of HDPE/MLLDPE higher than HDPE/LLDPE. In case of, MLLDPE content at 10% the value of tensile strength 25.18 MPa and MLLDPE content at 20% the value of tensile strength 21.84 MPa. However, tensile strength of HDPE is 25.23 MPa. Therefore, should be considered the MLLDPE content by evaluation other mechanical properties.

4.1.2 Elongation

There were significant differences observed between tensile strength and elongation at break of the three types of blends; the elongation increases as more MLLDPE content is in the blend as shown in Figure 4.2. The graph shows the elongation of the blends slightly increased from 10% to 20% MLLDPE content, and significantly increasing at 30% to 40% MLLDPE content. The elongation depends on the amorphous part of the molecule, which contains the segment of freely mobile chains [12]. Due to the LLDPE amorphous phase being greater than with HDPE, a higher LLDPE content in the HDPE/LLDPE blend will increase the amorphous phase, which will lead to a higher free volume; the free volume could allow easy to move the chain when stress is applied. Consequently, the blended sheet has a higher elongation than HDPE sheet. The result in this present study is different from the work by A.K. Gupta. He found that the elongation at break decreased, with respect to its value for HDPE with increasing LLDPE content of the blend up to 50% and then remained almost unchanged on further addition of LLDPE up to 70% [14,22]. The cause of the different result come from the difference of sample preparation, by injection and compression molding, extruded sheet and blown film. He suggested that the break occurred before

the LLDPE component contributed to the elongation of the sample beyond the limit of maximum elongation of HDPE [14].

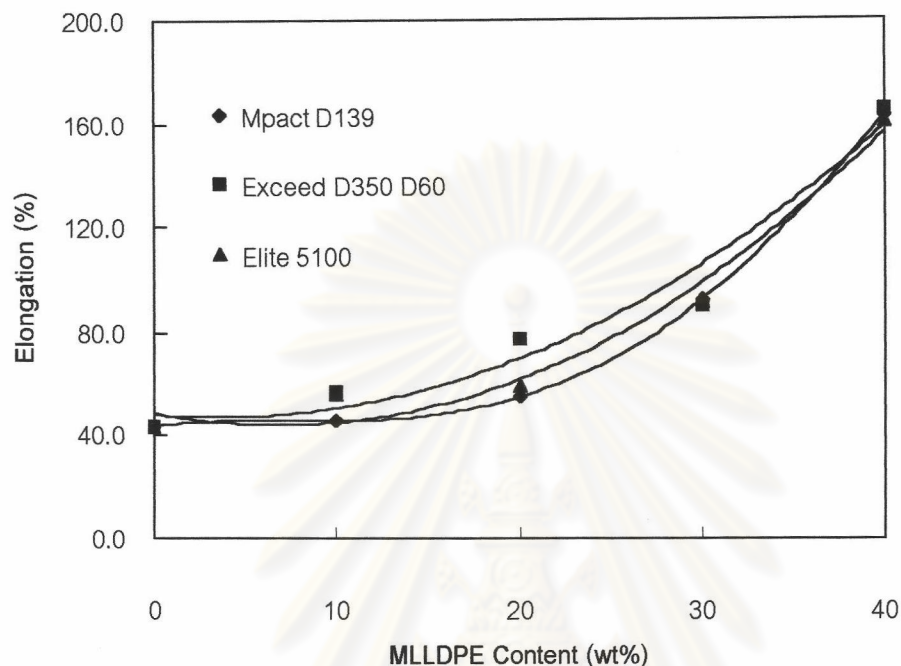


Figure 4.2 Elongation at break of HDPE/MLLDPE.

For the sheet and blown film process, the molecule is significantly oriented. Therefore, when the force is applied during the elongation testing, the LLDPE component can contribute to the elongation. MLLDPE has a higher volume fraction of amorphous phase, not only control short chain branching distribution but also molecular weight distribution [23,24]. The effect of incorporated MLLDPE on the elongation of the sheet is shown in Figure 4.2 and Table A-2. The results show a considerable increase in elongation with higher MLLDPE content, high elongation, therefore HDPE/MLLDPE sheet which has a higher elongation than HDPE is exceeding the industrial sheet requirement.

The pick up truck liner application requires stiffness and lower elongation. However, elongation of HDPE/LLDPE blends lower than HDPE/MLLDPE blends.

Therefore, the MLLDPE content should be considered and evaluated by other mechanical properties.

4.1.3 Flexural Modulus Testing

A measure of the strain imposed in the outermost fibers of a bent specimen. So the variation of flexural modulus with various contents of MLLDPE in three blends are shown in Figure 4.3 and Table A-4.

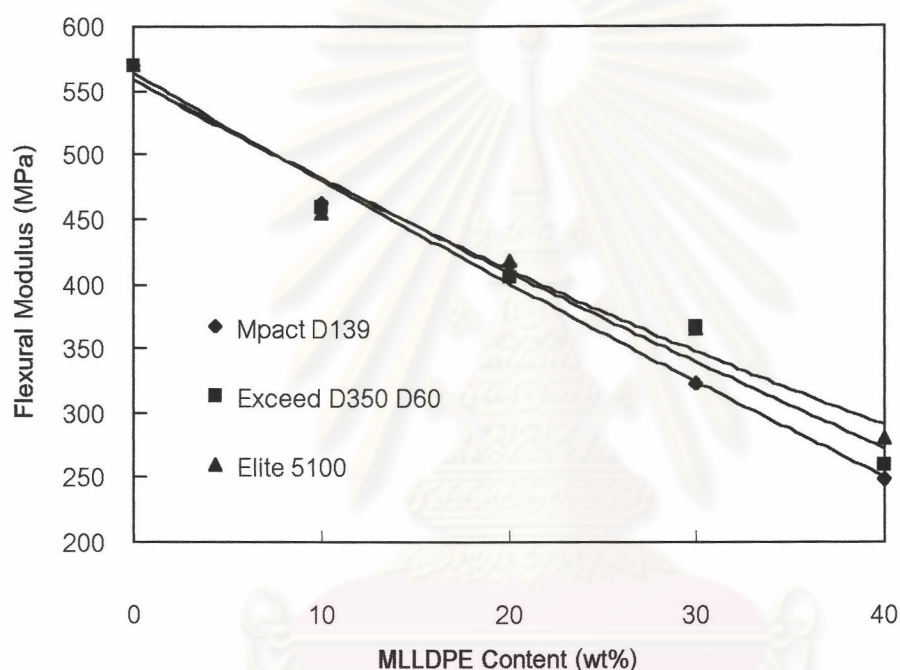


Figure 4.3 Flexural modulus of HDPE/MLLDPE sheet at various contents of MLLDPE.

The graph shows the flexural modulus of the blends containing MLLDPE 10% to 40%. The flexural modulus decreased significantly when the MLLDPE content increased. This means that the sheet has more softness, because the amorphous phase in the MLLDPE contains the flexible chain segment which can respond quickly to the applied stress or load. Since MLLDPE has a higher volume fraction in the amorphous phase than HDPE, consequently, HDPE/MLLDPE sheet is softer than HDPE sheet. A. K. Gupta *et al.* [14] not only reported tensile strength but also a

flexural property was studied. Normally the flexural moduli of MLLDPE or LLDPE are lower than these of HDPE. In the case of the HDPE/MLLDPE blend, both flexural modulus and flexural strength are lower than those of HDPE. The decrease of the flexural modulus with increasing LLDPE content is sigmoidal, while the decrease in flexural modulus is quite rapid up to 50% LLDPE content. Consequently, the variation of the flexural modulus depends on whether the two polymers are in a sufficiently large proportion or not. In addition, the flexural modulus of HDPE/MLLDPE blend at 10% MLLDPE content is 455 Mpa. However, flexural modulus of HDPE is 570 Mpa. Therefore, the MLLDPE content should be considered and evaluated by other mechanical properties.

4.1.4 Impact Strength

The variation of the Izod impact strength of HDPE/MLLDPE blends at various contents of the three blends are shown in Figure 4.4 and Table A-3. The graph shows the values of impact strength of the blends at 10% to 40% MLLDPE content. It could be observed that when the MLLDPE content in the blend increased to 10% the impact strength increased gradually until the MLLDPE content reached 20%, the impact strength slightly increased thereafter with increase of 30% to 40% MLLDPE content. The result obtained shows impact strength has increased considerably. Y. Zhao [25] found that both HDPE/MLLDPE and HDPE/LLDPE can be cocrystallized. The formation of crystalline may result from the merging of individual crystalline in the growth process of the crystallization. In this study, HDPE/LLDPE film has a lower impact strength than HDPE/MLLDPE film; the cause could be that HDPE/MLLDPE has more completed cocrystallization than HDPE/LLDPE. The complete cocrystallization comes from the branches of MLLDPE and can be more included in the crystal lattice during the cocrystallization process [25], while with the HDPE/LLDPE, the side group containing segments of LLDPE would remain outside the cocrystalline regions in the HDPE/LLDPE blend [26]. Since cocrystallization reduced the quantity of

crystalline due to merging of the crystalline, then HDPE/MLLDPE has less crystalline amorphous interphase than HDPE/LLDPE.

Refer to section 4.1.1 HDPE/MLLDPE had smaller size of lamella stacks than HDPE/LLDPE, then HDPE/MLLDPE film should have a higher impact strength than HDPE/LLDPE film. The dart impact strength at 20% MLLDPE content remained almost unchanged on further addition of MLLDPE up to 40% probably due to the maximum cocrystallization between HDPE and MLLDPE. Furthermore, the technical paper of metallocene polyethylene resin manufacturers are developing film impact strength for the metallocene polyethylene film industry was reported by William M. White [23]. The impact of HDPE/MLLDPE at 40% MLLDPE content showed an increase of 150 g; whereas dart impact of HDPE is 50 g. In addition, the technical paper of ExxonMobil MLLDPE exceeded D350 D60, which was presented by T. Tangnirunkul. The MLLDPE has a dart impact strength five times more than LLDPE. The impact strength of a pick up truck liner is the most important requirement; accordingly HDPE/MLLDPE sheet has the advantage for the automobile industry.

However, HDPE/MLLDPE blends can be used all MLLDPE content, when put higher MLLDPE content the cost must be considered.

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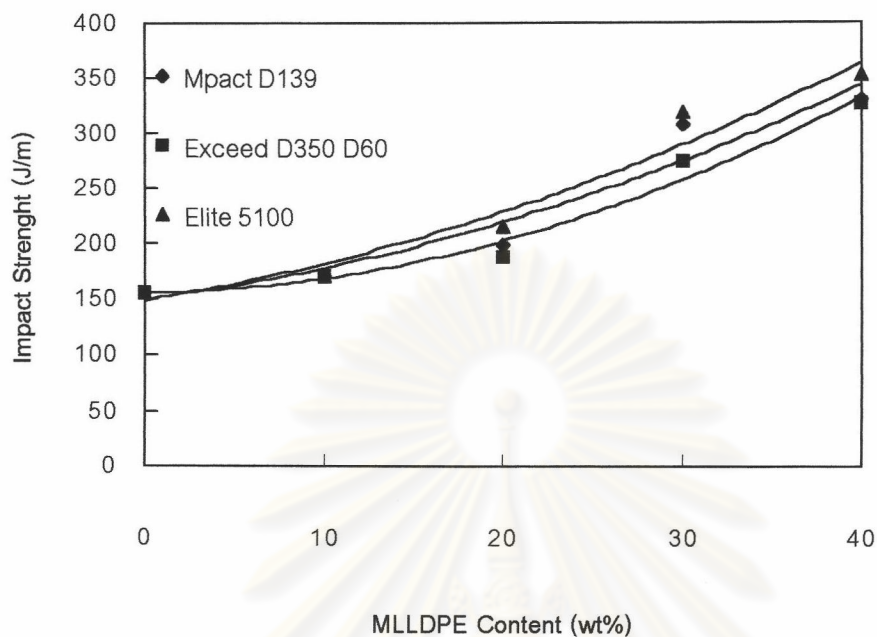


Figure 4.4 Impact strength of HDPE/MLLDPE blends at various contents of the three blends

4.1.5 Heat Distortion Testing

The heat distortion temperature (HDT) or deflection temperature under load (DTUL) denotes the maximum temperature at which a polymer can be used as a rigid material. The heat distortion temperature may also be considered as the upper temperature limit at which the material can support a load for any appreciable time. Thus the HDT or DTUL is a very practical and important property of a polymer [27]. Figure 4.5 shows the heat distortion temperature of HDPE/MLLDPE blends at various contents of the three blends. It can be seen that, HDPE has a higher heat distortion temperature than all HDPE/MLLDPE blends for all types of MLLDPE. It was found that the increase in MLLDPE content in the three blends decreases the flexural modulus and the heat distortion temperature. It is to be observed that the influence of the MLLDPE content at 10% to 40% shows little difference in the heat distortion temperature. In principle a blend of the two polymers

with different heat distortion temperatures, the HDPE rich blend must show a higher heat distortion temperature than the MLLDPE rich blend. However, heat distortion temperature of the blends for all MLLDPE content suited for the pick up truck liner.

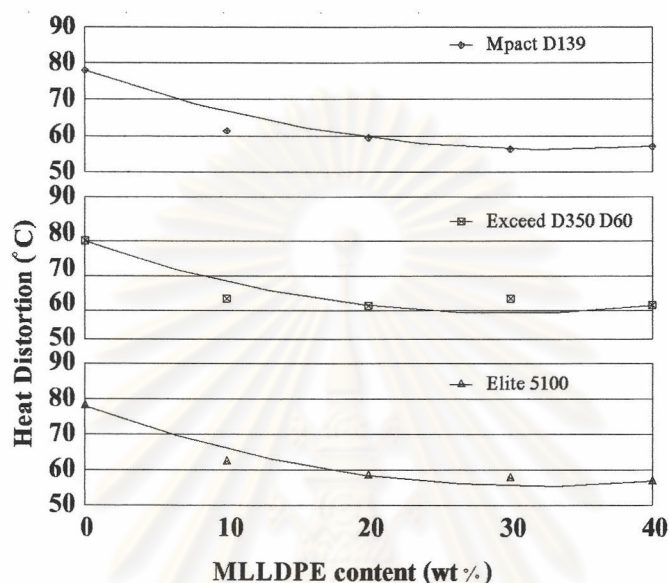


Figure 4.5 Heat distortion temperature of HDPE/MLLDPE blends at various contents of the three blends.

4.1.6 Comparisons of the Mechanical Properties of HDPE/MLLDPE Blends

Table 4.1 shows the comparison of mechanical properties of HDPE/MLLDPE blends at various contents of the three different MLLDPE resins. It was found that with all three different MLLDPE resins have the tensile strength, flexural modulus and heat distortion temperature properties of HDPE/MLLDPE blends decreased. The impact strength and elongation at break increased with increasing MLLDPE content of the blends between 20% and 30% MLLDPE contents. In addition, it can be seen that the MLLDPE from Elite 5100 had the highest impact strength value, when compared with all of them. Consequently, the advantage of Elite 5100 was its highest impact

strength value, whereas it compromised other mechanical properties, which means that the Elite 5100 at 20% and 30% MLLDPE contents were suitable for the physical property study. However, in order that we might get more data, the melt flow index, and density with different MLLDPE resin were evaluated. The dynamic mechanical thermal analysis were tested at 20%, 30%, and 40% MLLDPE contents of Elite 5100, whereas was tested at 30% MLLDPE content of Mpact D139 and Exceed D350 D60.

Table 4.1 Comparison of the mechanical properties of HDPE/MLLDPE blends.

MLLDPE (wt%)	Tensile Strength (Mpa)			Elongation at Break (%)		
	Mpact	Exceed	Elite	Mpact	Exceed	Elite
	D139	D350 D60	5100	D139	D350 D60	5100
0	25.23	25.23	25.23	43.77	43.77	43.77
10	25.18	25.02	24.70	45.64	56.90	55.84
20	24.11	24.39	24.49	55.03	77.27	59.36
30	21.84	21.65	21.65	92.33	90.08	91.37
40	19.56	20.75	18.76	162.7	165.3	160.6

Table 4.1 Comparison of the mechanical properties of HDPE/MLLDPE blend
(continued).

MLLDPE (wt%)	Flexural Modulus (Mpa)			Impact Strength (J/m)			Heat Distortion (°C)		
	Mpact	Exceed	Elite	Mpact	Exceed	Elite	Mpact	Exceed	Elite
	D139	D350 D60	5100	D139	D350 D60	5100	D139	D350 D60	5100
0	570.68	570.68	570.68	156.2	156.2	156.2	78.0	78.0	78.0
10	462.42	459.68	455.02	171	170.6	171	61.4	61.6	62.4
20	415.6	405.92	418.18	198.8	187.4	214.4	57.7	59.5	58.5
30	323.5	367.58	365.86	307.6	273.6	318.2	56.4	61.5	57.8
40	249.3	259.88	281.28	330.2	326.6	351.2	57.1	59.6	56.9

4.2 Physical Properties of HDPE/MLLDPE Blends

This section shows the trend of compatibility, percentage of crystallinity, morphology of the HDPE/MLLDPE blends and melts flow index and also density. In addition, melt flow index not only shows the trend of compatibility but also suggests other ways of studying processability.

4.2.1 Melt Flow Index (MFI)

The results of MFI are shown in Figure 4.6. It was found that the melt flow index (MFI) of HDPE/MLLDPE blends increased with increasing MLLDPE content and this effect is particularly sensitive in the 30% of MLLDPE content. Thereafter weight percentage of MLLDPE has less influence on MFI. This could probably explained that blending of only a small percentage (<30%) of MLLDPE brings very noticeable effects on both the processing characteristics and the mechanical properties of the finished products. The mixing materials with a different melt flow index, the value of MFI of blended HDPE/MLLDPE was estimated using the equation 4.1 [28] and the result are shown in Table 4.2. It can be seen that MFI only fitted in with 10 to 20% MLLDPE contents. When high MLLDPE contents were involved, the deviation between MFI from calculated (MFI-C) and MFI from measurement (MFI-M) could be as high as 30% or even 40%. However, a linear plot of MFI-C against MFI-M revealed that MFI-C and MFI-M could be very well correlated. A comparison between MFI-C and MFI-M obtained from equation 4.1 was made and shown in Table 4.2. It can be seen in the the table that the overall average percentage difference between the experimental and calculated MFI was about 30% at load 2.16 kg. In addition it could be pointed out that such a linear relationship between MFI-C and MFI-M was also found to be valid at 190 °C and 21.6 kg test conditions, which are also common testing conditions for polyethylene. Under this condition MFI-C

and MFI-M the value more easily read and the overall average percentage differences between the experimental and calculated MFI was about 4%.

However, those data appeared to be more linear as compared with data obtained from the measurement conditions mentioned previously. This can be ascribed to facilities in performing the MFI test when a 21.6 kg load was involved because of the MFI of HDPE lower than 1.0. Thus theoretically, it seems that the blending was homogenized and all melt flow index of HDPE/MLLDPE blends can be used.

$$\text{MFI blend} = 10^{[(W1 \cdot \log \text{MFI } 1) + (W2 \cdot \log \text{MFI } 2)]} \dots\dots\dots \text{Eq 4.1}$$

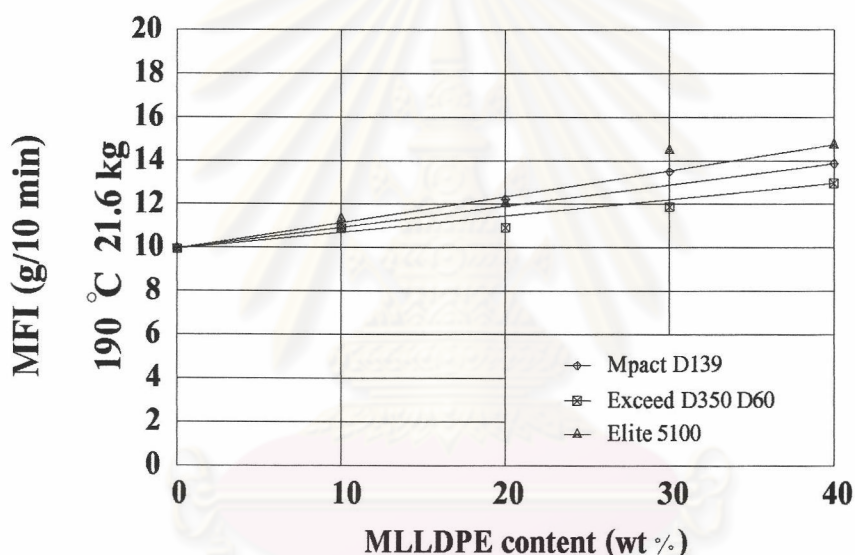


Figure 4.6 Melt flow index of HDPE/MLLDPE blends at various contents of the three blends from measurement.

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Table 4.2 Melt flow index of HDPE/MLLDPE blends at load 21.6 kg from experiment and calculation (g/10 min) at various contents of the three blends from measurement.

MLLDPE (wt%)	Mpact D139		Exceed D350 D60		Elite 5100	
	Experiment	Calculation	Experiment	Calculation	Experiment	Calculation
0	9.94	10.00	9.94	10.00	9.94	10.00
10	10.89	10.77	10.89	10.52	11.32	11.01
20	12.23	11.61	10.92	11.05	12.03	12.13
30	13.50	12.50	11.87	11.62	14.48	13.36
40	13.86	13.47	12.97	12.22	14.72	14.71

4.2.2 Density

Density was determined by the density gradient column technique. Unlike melt flow index, the density of blended HDPE/MLLDPE was found to follow an additivity relationship. Therefore, for a binary system equation 4.2 [29] offers a good way to predict the density of blended HDPE/MLLDPE. In addition, Figure 4.7 shows the density of the HDPE/MLLDPE blends. In this test with increasing of the MLLDPE content, the density of the HDPE/MLLDPE blends decreased because MLLDPE has a lower density than HDPE. Normally, HDPE resin density is about 0.948 g/cc whereas MLLDPE resins of the three types have an average value of 0.917 to 0.920 g/cc which means that the density of blended resins are similar to melt flow index of blends. Except for the fact that linear relationship between melt flow index and density was reversed. As revealed in Figure 4.2, the difference between calculated value and experimental value was very small as shown in Table 4.3 and Figure 4.7, as stated by “ rule of mixture ”, it indicated that the blending shall be homogenized, which confirmed the melt flow index

data. Thus it was found that the all density of HDPE/MLLDPE blends can be used.

$$1 / D \text{ blend} = W1 \times (1 / D1) + W2 \times (1 / D2) \dots\dots\dots \text{Eq. 4.2}$$

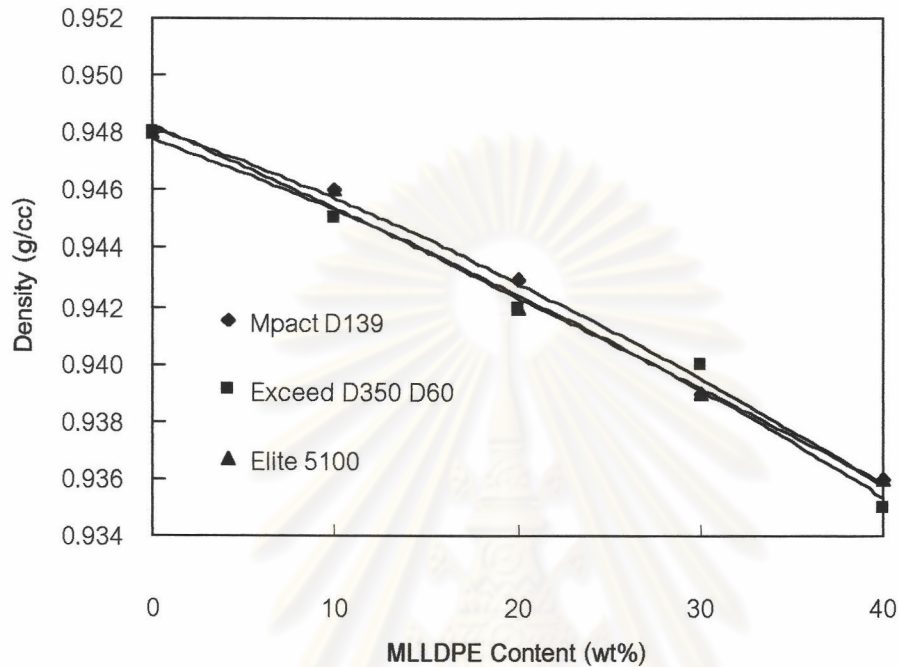


Figure 4.7 Density of HDPE/MLLDPE blends at various contents of the three blends.

Table 4.3 Density of HDPE/MLLDPE blend from experiment and calculation at various contents of the three blends

MLLDPE (wt%)	Mpact D139		Exceed D350 D60		Elite 5100	
	Experiment	Calculation	Experiment	Calculation	Experiment	Calculation
0	0.948	0.948	0.948	0.948	0.948	0.948
10	0.946	0.945	0.945	0.945	0.946	0.945
20	0.943	0.942	0.942	0.941	0.942	0.942
30	0.939	0.939	0.940	0.939	0.939	0.939
40	0.936	0.936	0.935	0.935	0.936	0.936

4.2.3 Differential Scanning Calorimetry (DSC)

DSC studies were carried out for all the blends. Appendices B1 - B12 and Figure 4.8 for HDPE/MLLDPE blends compared with its individual material. The HDPE/MLLDPE showed only one crystalline peak, the same as in the previous study by E. Karbasheswoki [32] concluded that the HDPE/LLDPE blending operation was successful because there appeared to be only one “crystalline” peak by using DSC. Consequently, the HDPE/MLLDPE blends in this present study are homogenous at every composition. The single crystallization exotherm characterizes the cocrystallinity of HDPE/MLLDPE. The cocrystallization of HDPE and LLDPE had been supported by Rana-SK [13]. He revealed that the HDPE/MLLDPE blend manifests a single crystallization exotherm which was ascribed to the cocrystallization between two constituting components. The similarity in their chemical structures may be accountable for their affinity toward % crystallinity. With the increasing of the MLLDPE content, a single peak was shifted to intermediate between the melting points of the components, thus the melt temperature of HDPE/MLLDPE blend decreased linearly by following a simple mixture rule. This result is the same as the other separate study by H. Lee [16] when the HDPE/MLLDPE blend was thought to be miscible in the crystalline phase. In this present study, the conclusion is that HDPE/MLLDPE is a miscible blend in the crystalline phase. Each DSC of MLLDPE shows two peaks of melt temperature. One of these two peaks probably arises from the other component, the long branch compound, which is added to mix with the MLLDPE to improve the processability of MLLDPE which has a lower melt temperature because MLLDPE has a smaller lamella size than LLDPE which requires lower energy to melt the crystalline. HDPE has a higher melt temperature than LLDPE because it has a higher crystallinity.

The DSC crystallization shows the area under the peak represents the heat of fusion of the HDPE/MLLDPE blends. The crystallinity is determined by comparing

the measured heat of fusion with the theoretical heat of fusion of 100% crystalline polyethylene of 290 J/g. The heat of fusion of 100% crystalline polyethylene was obtained from the Mettler Toledo. Consequently, the area under the peak of HDPE/MLLDPE blends decreased with increasing MLLDPE content as shown in Figure 4.8, due to the increasing of the amorphous phase. Thus, the percent crystallinity of HDPE/MLLDPE blends at 20%, 30% and 40% MLLDPE contents were decreased from 58.40%, 53.70% to 52.63% respectively. It was found that HDPE/MLLDPE with a 20% content has higher % crystallinity than HDPE/MLLDPE with 40% content. The percent crystallinity of the blend was increased. The hardness and strength were increased.



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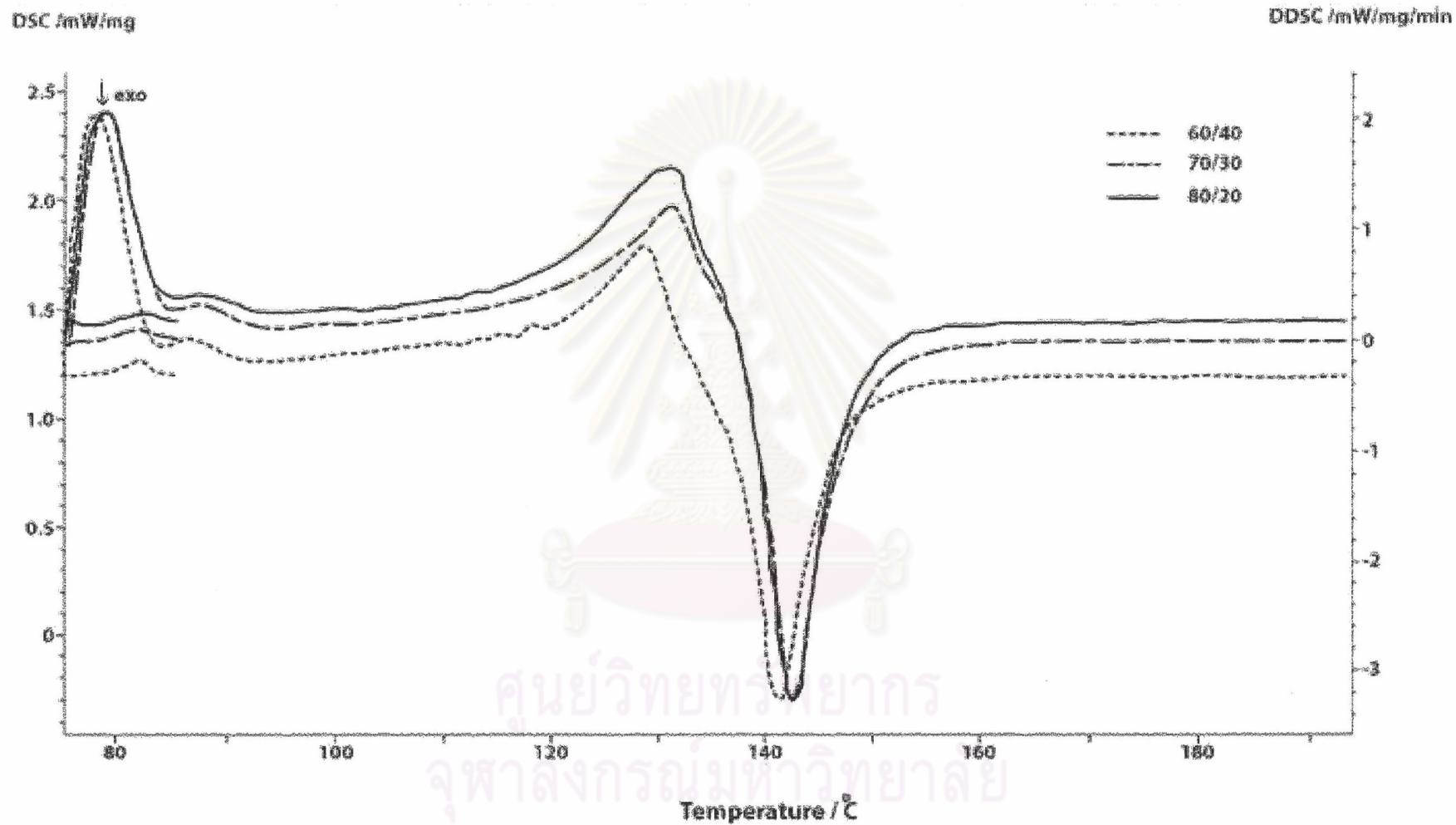


Figure 4.8 DSC of HDPE/MLLDPE blend 60/40, 70/30, and 80/20, MLLDPE from Mpacct D 139

4.2.4 Dynamic Mechanical Thermal Analysis (DMTA)

The glass transition temperature of HDPE/MLLDPE blends 80/20 and 70/30, were investigated by the plots of $\tan \delta$ versus temperature as shown in Figures 4.9-4.12. Their glass transition temperatures are -112.3°C , -110.9°C , -104.8°C , and 105°C respectively. In the case of HDPE/MLLDPE only one T_g was observed for each blend. Similar results had been reported by Hoseok Lee *et al* [16], i.e., the glass transition of HDPE/MLLDPE blends were linearly shifted from -112°C (designated the T_g of HDPE) to -105°C . They assumed the miscible blend in the amorphous phase. However, in this research the glass transition temperatures of every HDPE/MLLDPE content are very close to each other. It is difficult to discuss miscibility of these blends with this information.

The T_{γ} peak of the $\tan \delta$ maximum peak is the glass relaxation of the $(\text{CH}_2)_n$ group. That is, the T_{γ} relaxation occurs in the amorphous regions and therefore its magnitude is a function of the volume of the amorphous polymer [30,31] with the incorporation of more amorphous species. With the intensity of T_{γ} peak, HDPE/MLLDPE has a higher volume fraction of the amorphous than HDPE.

The T_{β} peak is attributed to the rotation of the side-branching group, especially of the portion of the molecule containing group. On the contrary, the T_{β} peak can be observed in Figures 4.9-4.12 but their presences are not so obvious visually. To clarify this behavior, E'' should be also analyzed. HDPE/MLLDPE blend has two T_{β} peaks, one peak is due to HDPE at about -60°C and the other belongs to MLLDPE at about -20°C . The T_{β} peak of HDPE is due to butane-1, the comonomer and the T_{β} peak of MLLDPE belongs to octane-1, the comonomer. If the blend is miscible, only one T_{β} peak will appear. Consequently, it can be concluded that the HDPE/MLLDPE blend is immiscible in the amorphous phase.

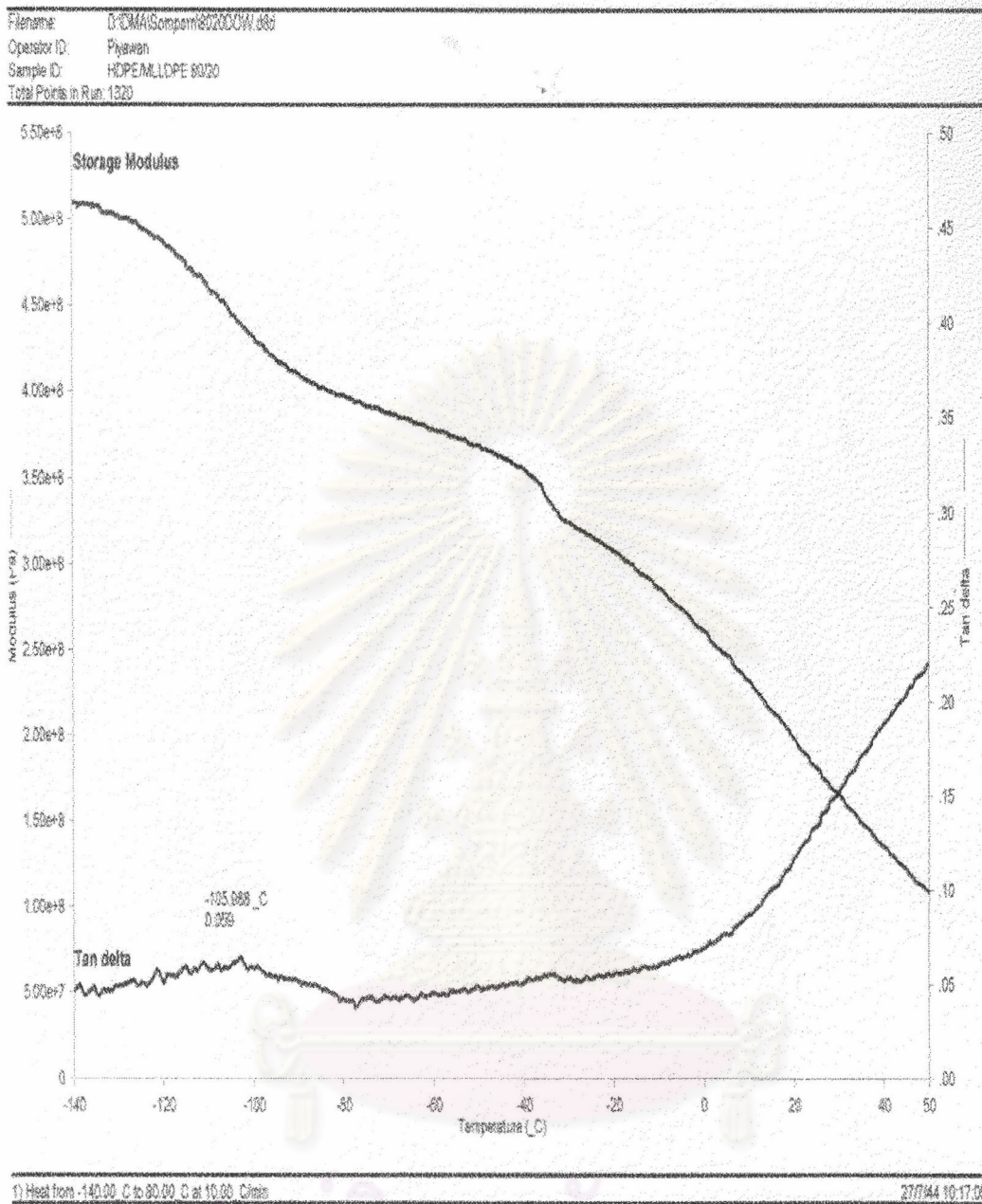


Figure 4.9 DMTA of HDPE/MLLDPE blend 80/20 using MLLDPE from Elite 5100.

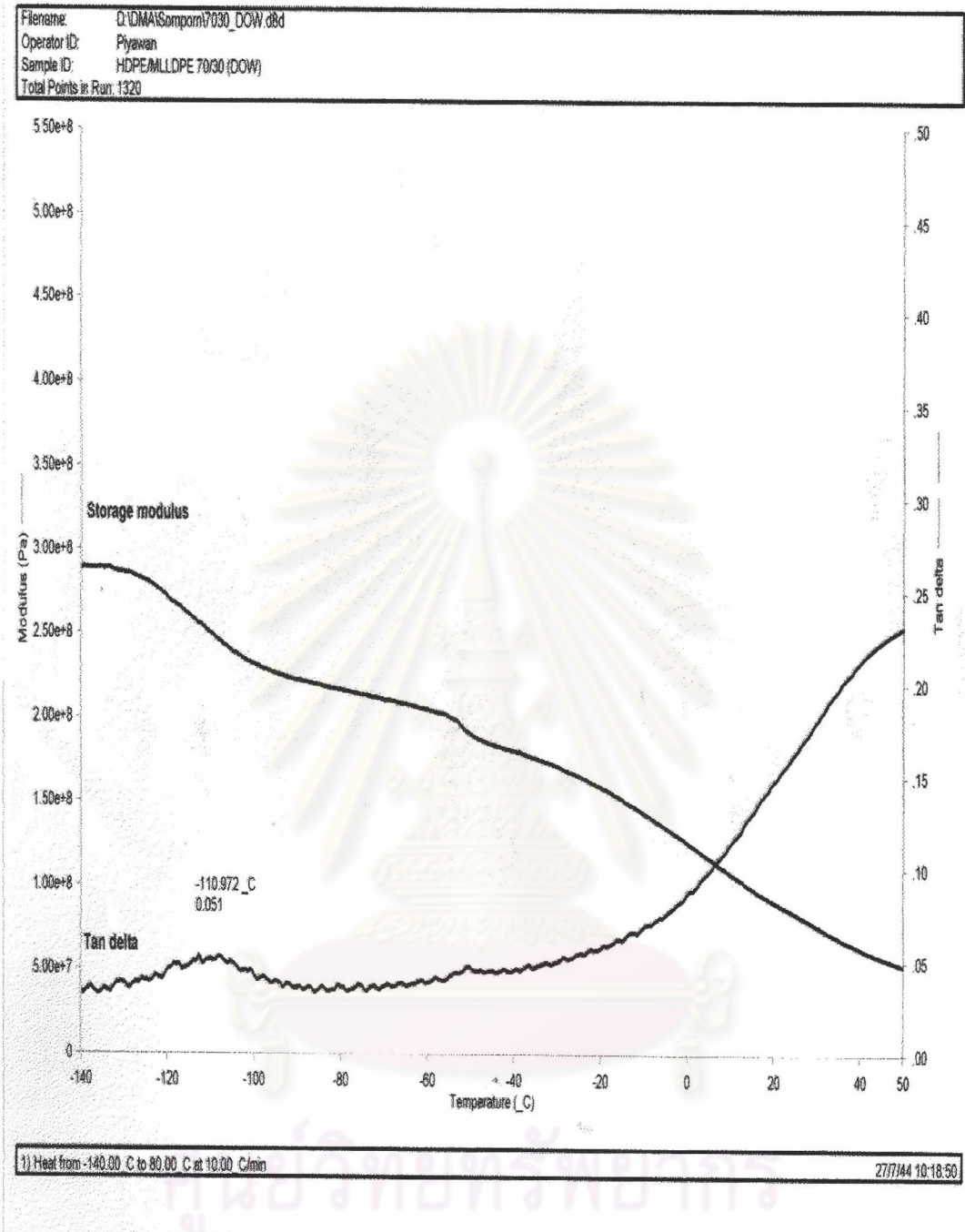


Figure 4.10 DMTA of HDPE/MLLDPE blend 70/30 using MLLDPE from Elite 5100.

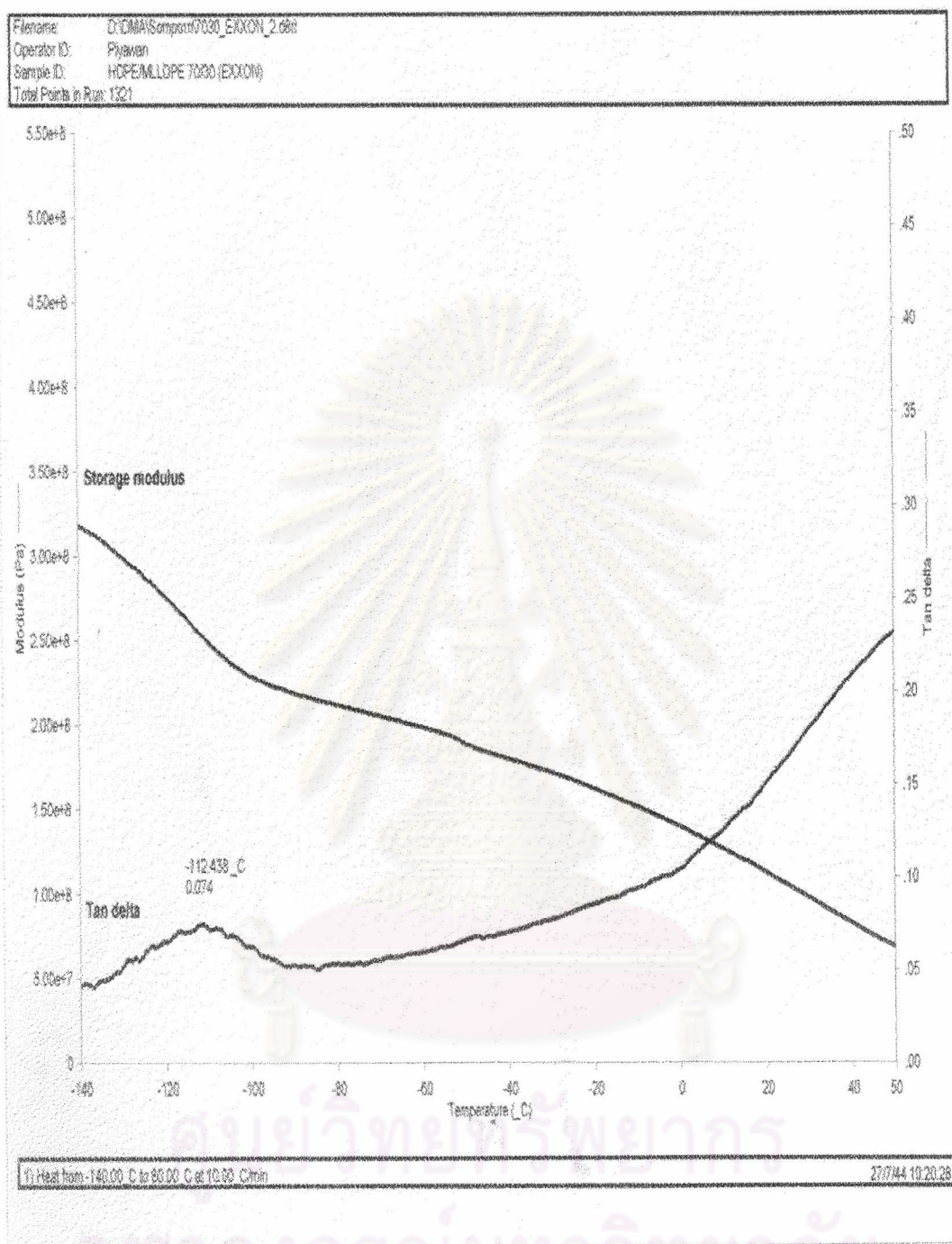


Figure 4.11 DMTA of HDPE/MLLDPE blend 70/30 using MLLDPE from Exceed D350 D60.

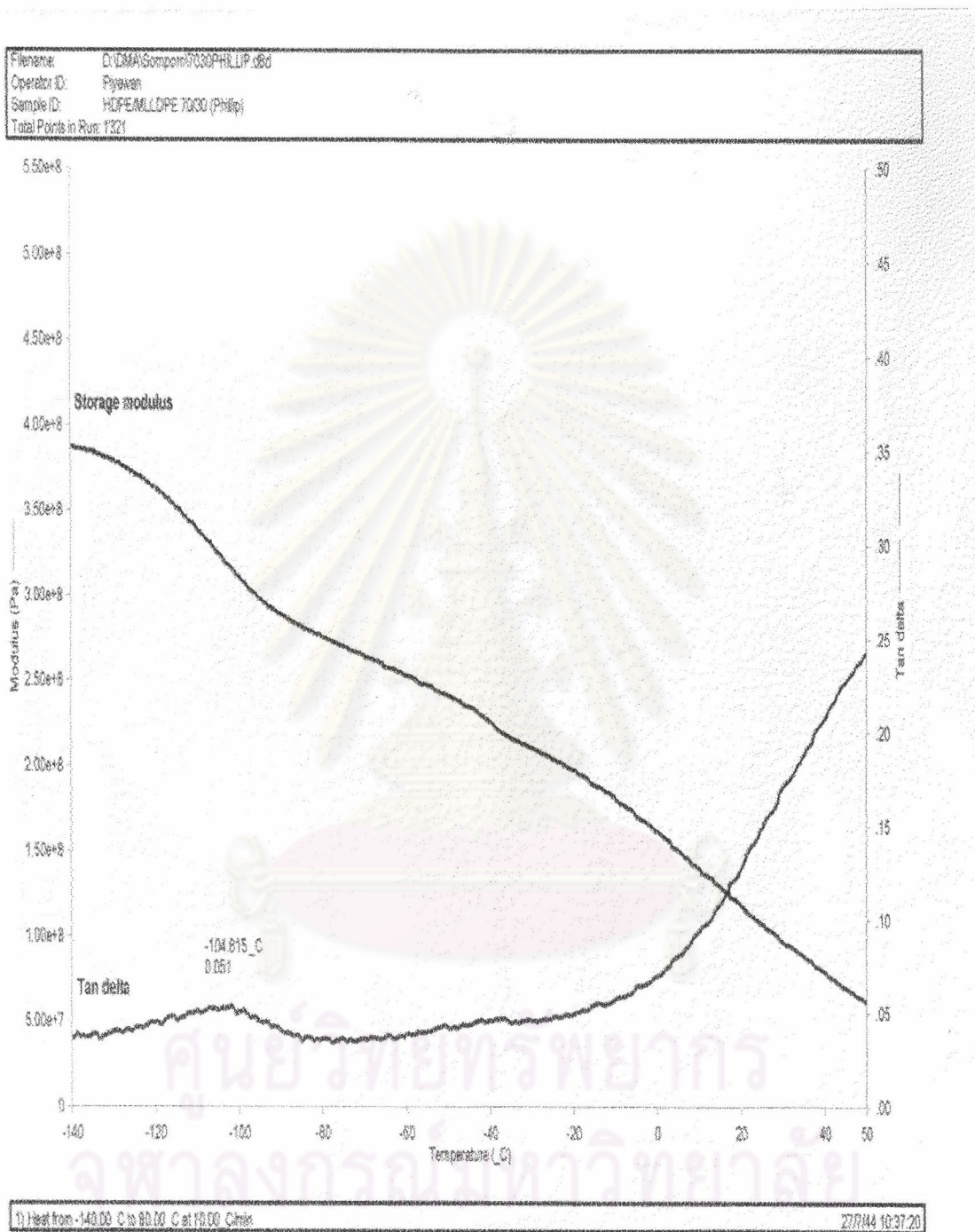


Figure 4.12 DMTA of HDPE/MLLDPE blend 70/30 using MLLDPE from Mpackt D139.

4.3 Sheet Sample Preparation and Friction Testing

4.3.1 Sheet Sample Preparation

In this study, polymer HDPE/MLLDPE sheet was prepared using the same conditions of the sheet extrusion machine as for producing HDPE sheet. In addition, the extrusion conditions should be similar between HDPE and HDPE/MLLDPE blends in that both had to use the polyolefin screw. However, in order to consider the result from the mechanical properties tested it was apparent that HDPE/MLLDPE blends at 80/20 and 70/30 % content were suitable for sheet extrusion in three grades of MLLDPE because of a compromise between flexural modulus and heat distortion temperature.

Furthermore, HDPE/MLLDPE blends at 20% to 30% MLLDPE contents have the impact strength adequate for the application without any substantial variation in tensile strength. Nevertheless, the MLLDPE used in this experiment are Elite 5100 and are chosen based on average molecular weight (M_w) because MLLDPE from Chevron Phillips Petroleum Mpack D139 has $M_w = 105,000$ and MLLDPE from ExxonMobil Chemical Exceed 350 D60 has $M_w = 106,000$ while MLLDPE from Dow Plastics Elite 5100 has $M_w = 110,000$. Despite the fact that the molecular weight of the three MLLDPE does not differ too much, in the long run with regard to cost of inventory, transportation and also import tax, the MLLDPE commercial grades Elite 5100, produced in Thailand, was suitable for this experiment.

In the preliminary study on the sheet, it was found that the heat capacity of the sheet rose when the MLLDPE content was higher than twenty percent, which affected the calender roll temperature and, thus the sheet stuck to the calender roll surface. From the data MLLDPE has a very narrow molecular weight distribution, and so the melt viscosity of the polymer at high shear rate is very high. It causes many effects, such as high screw torque, high die pressure

and generates higher extrusion heat. However, at twenty percentage content of MLLDPE it was unnecessary to adjust the calender roll temperature because of a content of still rich HDPE blend, whereas above twenty percentage content of MLLDPE a little water cooling for calender roll adjustment was needed.

4.3.2 Friction Testing

The information obtained from the mechanical properties study indicated that the HDPE/MLLDPE blends at 20% to 30% MLLDPE content, where the following results were obtained. Compromise among the tensile, elongation and impact strengths which have moderate engineering value on the one hand, while it cannot be denied that whenever we have the high impact strength and elongation at break in contrast we have the decreased tensile strength and flexural modulus. In common with tensile strength versus impact strength have a compromise between flexural modulus and heat distortion temperature. As a result, the coefficient of friction (C.O.F) study examined the effects of static friction of HDPE/MLLDPE blends by the friction tester. In Table 4.4 shows the value of the coefficient of friction at 20% to 30% MLLDPE content. In this table, the C.O.F increased gradually, and the upward trend continued when the MLLDPE content increased. Industrial sheet for pick up truck liner usage needs the higher co-efficient of friction than conventional HDPE sheet because the pick up truck liner does not need slip properties during load carrying. In this case, significant differences were found among 20% and 30% MLLDPE content; Due to the fact that at 30% MLLDPE content the average value of C.O.F increased to 0.31 or approximately 15% higher than 20% MLLDPE content and approximately 40% when compared with conventional HDPE sheet. By comparing the HDPE/MLLDPE sheet at 30% MLLDPE content has a adequate C.O.F and meets the requirement of the pick up truck liner industry.

Table 4.4 Static-coefficient of friction of HDPE/MLLDPE blends at 80/20 and 70/30.

HDPE	HDPE / MLLDPE	
100	80 / 20	70 / 30
0.22	0.27	0.31

4.4 Sheet Orientation

Oriented thermoplastic sheets are one of the most sensitive sheet materials to handle in the heating and forming cycles of the thermoforming process. As mentioned earlier, loss of orientation is very close to the softening temperature of the thermoplastic sheets, thus precise and fast heating and forming cycles must be maintained. Evenly balanced orientation across the machine direction width or width of cut sheet or roll is the ideal condition. However, fluctuations of unevenness are often encountered, which means that the orientation stretch in the machine direction does not give consistent orientation across the width of cut sheet. Whenever such an unevenly balanced machine direction oriented high density polyethylene sheet is exposed to heat, the deorientation forces will distort the sheet. The levels of unbalanced orientation and its limits of usefulness should be judged differently with each product type. Some products are less vulnerable than others with regard to using out-of-balance HDPE sheets. Usually the deeper drawn, more intricately designed parts demand a better – balanced orientation than do shallow, simple thermoformed parts. There are various ways to check for imbalanced orientation. However the imbalanced orientation testing in this study, it is suitable for HDPE sheet. Consequently, the result from examination of the HDPE/MLLDPE blends sheet at 80/20 and 70/30, (%) by weight as shown in Table 4.5.

Table 4.5 Sheet Orientation of HDPE/MLLDPE (Elite) at 80/20 and 70/30.

HDPE/MLLDPE	Level of orientation (%)		
	Sample 1	Sample 2	Sample 3
80 / 20	40 %	38 %	40 %
70 / 30	48 %	48 %	46 %

Table 4.5 shows the data collected by sheet extrusion process. It summarized the level of orientation of HDPE/MLLDPE blends at 80/20 and 70/30. The findings of the study were that the orientation study results significantly conformed with conventional HDPE sheet which in the pick up truck liner thermoforming process requires an orientation of 40% to 50%.

4.5 Extrusion Processability

Basically, for the extrusion processability study the components of the process, which had three most important ones as shown in Figure 3.3 must be understood. The first is the extruder, the second is the flat die, the third is the calender roll stack. The extruder is the main component, the heart of the entire system [3]. Besides being the most costly component, this piece of machinery uses the most energy. The extruder receives the HDPE/MLLDPE, then the pellets was melt and pressurized into the flat die. In this experiment, only HDPE/MLLDPE blends at 20% and 30% of Elite MLLDPE content were selected. It was found that the same condition as conventional HDPE could be used. However, in extrusion processability. the electrical current of the extruder motor increased 15% but it was acceptable.

The second component of the extrusion system is the flat die. At this point, the final shape of the melt flow is determined. Generally, for sheet, used mostly for thermoforming, the molten resin is forced through a flat die. The die has a “ coat hanger ” shaped manifold and a restrictor bar to maintain uniform material flow throughout. The die lips are adjustable and control the die gap (opening), thereby regulating the thickness of the material as it is extruded from the die. Adjusting the die

is tedious and great care must be taken to achieve ultimate uniformity in the sheet. Inappropriate die adjust can cause a sheet thickness variation. It was found that HDPE not only was there difficulty controlling the melt uniform across a flat die but there was also more thickness variation than HDPE/MLLDPE blends at those content. The melt flow index of blended HDPE/MLLDPE was obtained to increase when MLLDPE content increased. Consequently, the benefit of HDPE/MLLDPE blends at 20% to 30% is that they are easy regulating the thickness of the melt polymer as it extruded from the die.

The third component of the extrusion process is the calender roll stack. This equipment is similar to that used in the calendaring process. The melt flow coming out of the flat die is nipped between two polished rolls and then threaded through an S shape on the two consecutive rollers. This combination of calender rolls is called the calender roll stack. The purpose of this vertical stack of calender rolls is first, to nip and set the desired sheet thickness, and second, to cool it to a crystalline form. The calender rolls are temperature controlled by circulating fluids and maintained at a constant temperature.

It was found that the roll temperature must be reduced, because HDPE/MLLDPE blends had melting temperature lower than HDPE. In addition, the HDPE/MLLDPE blends had heat of fusion lower than HDPE. The advantage of reducing calender roll temperature is that it is easy to control thickness variation.

As discussed earlier, it was found that the production of the sheet or film by extrusion imparted shear and heat to the polymer resin which affected the processability performance of the sheet after the thermoforming process. The temperatures of the extruder and screw speed were set constant in order to evaluate extrusion processability of HDPE/MLLDPE blend. Consequently, the more finished products of HDPE/MLLDPE blends were obtained comparing to the HDPE at the same length of production time. Thus it leads early completion of melting and thus will shorten mixing time. This is mainly due to MLLDPE content which provides the high

shear viscosity of HDPE/MLLDPE blends. However the extruder should be higher power load approximately 15% than HDPE.

4.6 Thermoforming Processability

Three different thermoforming sheets using elite MLLDPE were used in this experiment, HDPE/MLLDPE blends at 80/20 and 70/30 content comparing with the conventional HDPE. Firstly, the thermoforming conditions of HDPE was used, oven temperature 295°C, mold temperature 85°C, heating time and cooling time 180°C to 90°C respectively. It was found that both HDPE/MLLDPE sheets were burnt at those conditions. To solve this problem the thermoforming conditions was reset. The best conditions for both blends were used, oven temperature 285°C to 230°C respectively. In addition, heating time and cooling time were 170°C to 60°C, respectively.

Basically cooling the part after forming is vital and can be even more time consuming than heating [4]. Therefore, it is important to select the appropriate cooling method for pickup truck liner. Most of the heat absorbed during the heating cycle must be extracted from the plastic part before it can be removed from the mold. Otherwise, distortions or warpage of the part may occur. When the part has been formed and the crystallinity level of the sheet reaches about 20% to 25%; observing the color of the sheet, it is subsequently stripped from the mold. The hot sheet is then exposed to ambient conditions and the part cools to room temperature. The sheet continues to crystallize during cooling. As a result, cooling time of the HDPE/MLLDPE blends formed part is shorter than the conventional HDPE formed parts because if the HDPE content is too high, crystallinity continues and the final part becomes brittle. This allows the formed parts to cool slowly and allows the thicker sections of the formed parts to continue to crystallize.

The difference between conventional HDPE and HDPE/MLLDPE blends is that the former needs a longer cycle time and higher oven temperature, whereas the latter require a shorter cycle time and lower oven temperature as shown in Table 3.4.

This indicates that with HDPE/MLLDPE blends there are more cycles, and consequently higher more productivity.

4.6.1 Sagging of Heated Sheet

The sag was determined by the temperature dependent tensile strength of the polymer [4]. Since sag is very important to the forming process care must be taken when heating sheet. The sagging distance was measured according to the distance of the photoelectric eye. It was set following the sheet sag and the data are obtained by analyzing the systematical parabolic model. Consequently, it was found that the sagging distance of HDPE/MLLDPE blend sheet was higher than HDPE. Therefore, the sagging distance increased in consequence of the thickness variation of pick up truck liner decreased. Consequently, HDPE/MLLDPE sheet has an advantage for the pick up truck liner products.

4.6.2 Pick Up Truck Formed Part Shrinkage

Figure 3.14 shows the pick up truck liner formed part shrinkage along the length of the part. The variations of formed part shrinkage of HDPE was 0.53% whereas HDPE/MLLDPE blends at 20% and 30% MLLDPE contents were shrunk from 1.32% to 1.58% respectively. However, the shrinkage rate should be controlled much less than 2.50%. Consequently, variations in shrinkage must be investigated before production.

This indicates that, pick up truck liner formed part shrinkage of HDPE/MLLDPE blends at 20% to 30% MLLDPE contents remains small in percentage shrinkage (1.15% ~ 2.50%). Thus, with HDPE/MLLDPE blends it can be concluded that both levels of pick up truck formed part shrinkage were accepted to the pick up truck liner products.

4.6.3 Reproducibility

In order to test for the reproducibility, the HDPE/MLLDPE blends at 70/30 content by weight using MLLDPE of Mpack D139, Exceed D350 D60 and Elite 5100 were prepared again. The mechanical properties were measured. The result was shown in the Tables A-9 to A-11. It was found that the tensile strength of HDPE/MLLDPE blends at those contents were the same value as in the previous study. Besides, in the case of elongation and impact strength there is a little fluctuation, which caused of the measured values and has minor deviation in terms of blending and sample preparation. However, the similarity between HDPE/MLLDPE blends of the three resins and HDPE/MLLDPE blends reproducibility is that they are homogenous in blending and also compatible. It is observed that every blends can be reproduced.



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