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Evaluation and Improvement of Mechanical, Thermal and Rheological Properties of Polypropylene (PP) using Linear Low Density Polyethylene (LLDPE)

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*Abstract— **for many years, polypropylene (PP) has been very successfully used for film blown, injection molded, and extrusion applications. This work aimed to study the effect of linear low density polyethylene (LLDPE) on mechanical, thermal and rheological properties of homopolymer polypropylene (PP) for injection molded application. In the experimental study, five formulations of PP and LLDPE viz. 90/10, 80/20, 70/30, 60/40 and 50/50 wt % were prepared for injection moulding machine. The mechanical properties such as flexural modulus and impact resistance were investigated. The thermal property such as heat deflection temperature (HDT) was evaluated. In addition, melt flow index (MFI) of the blend have been determined. Results showed improvement on the mechanical, thermal and rheological properties. It is then concluded that the optimum composition of PP/LLDPE blends provided the best mechanical, thermal properties and a moderate rheological property is 70/30.***

Index Terms— PP; LLDPE; Blend; Mechanical; Thermal; Rheological Properties.

I. INTRODUCTION

Commercial polypropylene (PP) is a thermoplastic material that is produced by polymerizing propylene molecules, which are the monomer units, into very long polymer molecule or chains. According to L.A.Utracki (2002, p.1035) there are a number of different ways to link the monomers together, but PP as a commercially used material in its most widely used form is made with catalysts that produce crystallizable polymer chains. These give rise to a product that is a semicrystalline solid with good physical, mechanical, and thermal properties [1]. Another form of PP, produced in much lower volumes as a byproduct of semicrystalline PP production and having very poor mechanical and thermal properties, is a soft, tacky material used in adhesives, sealants, and caulk products. The above two products are often referred to as isotactic (crystallizable) PP (i-PP) and atactic (noncrystallizable) PP (a-PP), respectively [1].

Well-known polypropylenes of commerce are particularly isotactic, semicrystalline, thermoplastic polymer mixtures. Although the polypropylenes of commerce have many desirable and beneficial properties, like Impact resistance, heat resistance, high stiffness, scratch resistance, they also possess some important drawbacks such as high viscosity, which results in a reduced throughput in many applications, such as for blown films, extrusion coating, foam extrusion and blow moulding. Further, in the production of blown films, a high stiffness can result in the creation of wrinkles on the film reel as the lay flattening of high stiffness materials is very critical [1].

According to a recent article in thermoplastics blend by D. G. Dikobe, A. S. Luyt (2010) and Ogah, A. O. and Afiukwa J. N (2012), blending of two or more polymers is a cheaper and more effective alternative, not only for the development of polymers with new properties, but also for recycling of greener materials [2],[3]. Polypropylene/polyethylene (PP/PE) blends are amongst polymer blends that were studied by various researchers [1]-[2]. There are three different types of PE, namely low-density polyethylene (LDPE), high density polyethylene (HDPE), and linear low-density polyethylene (LLDPE) were used to modify the physical and mechanical behavior of PP by forming physical blends [2]. Yi Liua, Shu-Cai Lia and Hong Liua (2013) described the melt rheological properties of LLDPE/PP blends compatibilizer by cross-linked LLDPE/PP blends (LLDPE-PP) [4].Another work done by Abu Ghalia, Mustafa A (2011) evaluated the mechanical, rheological, and thermal properties of calcium

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carbonate filled polypropylene / linear low density polyethylene composites [5].PP in its applications are often limited due to its low impact strength and Young's modulus, particularly at low and high temperature loading conditions. These PP drawbacks can be considerably improved by blending PP with other polymers [2]. Blending of PP and different PEs largely depends on the miscibility or immiscibility of the two components. PP and LDPE or HDPE are generally considered immiscible in the whole composition range and shows a remarkable phase separation during cooling/crystallization [2].
On the other hand, PP and LLDPE are considered to be compatible in the liquid state. However, PP/LLDPE miscibility is restricted by the processing conditions, composition and high temperatures. If a blend of PP and LLDPE is cooled from a miscible melt it may separate into two phases resulting in an immiscible blend [2]-[4]. D. G. Dikobe, A.S. Luyt (2010) studied of the morphology and properties of PP/LLDPE/wood powder and MAPP/LLDPE/wood powder polymer blend composites [6].

2. Experimental work

Polypropylene (PP) Materials:
Supplied by Khartoum Petrochemical Company (KPC, Sudan), in powder with the following particulars:

Trade name	PP-114
Density	0.914 g·cm–3
Melting point	230°C
Melt flow index (MFI)	30g/10 min (230°C, 2.16 kg).
Tensile stress at Yield	27.5MPa
Flexural Modulus	950MPa
Izod impact resistance	20 J/m
Heat deflection temperature	71°C

Linear low density polyethylene (LLDPE):
Supplied by SABIC (Saudi Arabia) in pellet with the following particulars:

Trade name	LLDPE-218N
Density	0.918 g·cm–3
Melting point	190°C
Melt flow index (MFI)	2g/10 min (190°C, 2.16 kg).
Melt temperature	185 - 205°C
Tensile stress at Yield	12MPa
Flexural Modulus	260MPa
Dart Impact Strength	5g
Vicat Softening Point	98°C

2.2 Methods (Preparation of the blends):
The blends of PP/LLDP were prepared according to the required compositions 90/10, 80/20, 70/30, 60/40 and 50/50 to make up a total of 300g. The samples were prepared in injection moulding machine at 180°C - 220°C. The processed samples were allowed to cool at room temperature for 48 hours and 50 ± 5 % humidity. Then different tests were carried out such as flexural modulus and impact resistance as mechanical test. In addition heat deflection temperature (HDT) as thermal test. Finally, the melt flow index (MFI) of the blend has been determined as rheological test. Isotactic polypropylene (PP), linear low density polyethylene (LLDPE), the compositions of blends to produce PP/LLDPE blends are shown in table 1.

Table1. Composition percentage of PP/LLDPE blends

No	Materials	
	PP (Wt %)	LLDPE (Wt %)
1	90	10
2	80	20
3	70	30
4	60	40
5	50	50

The flexural test:

The flexural test of the blends was carried out on a Houndsfield universal testing machine according to the ASTM D790. A computer was connected to the Houndsfield load cell and data acquisition program recorded the force measured by the load cell. Test specimens were molded in a size of 12.7 mm (width) and 3.2 mm (thickness). Prior to the test all specimens were kept at room temperature at least 48 h and 50 ± 5 % humidity.

Impact test:

Izod impact strength values of the blends were evaluated with a Resil impact test instrument according to the ASTM D256 test procedure at room temperature. Izod impact tests specimens were molded in a size of 12.7 mm (width), 3.2 mm (thickness) and notched width 10.20mm. Prior to the test all specimens were kept at room temperature at least 48 h and 50 ± 5 % humidity.

Heat deflection temperature (HDT) test:

The thermal properties of the blends were evaluating through heat deflection temperature (HDT) test. The test was carried out on a Ceast tester machine according to the ASTM D648. The tests specimens were molded in a size of 12.7 mm (width), 3.2 mm (thickness). Prior to the test all specimens were kept at room temperature at least 48 h and 50 ± 5 % humidity.

Melt flow index (MFI) test:

The melt flow index (MFI) PP/LLDPE blends were determined by a Shijiazhu Ang Zhong Shi testing machine according to the procedure ISO 1133:2005 method and facilities of automatic cutting. The die diameter of 2.095mm, temperature control range of 100-400oC, charge canister diameter 9.55mm, length 160mm and applied dead mass of 325g. The melt-flow index rate was quoted as a measure of the mass in grams of melted polymer extruded in 10 minutes through the capillary die.

3. Results and discussion:

3.1 Mechanical properties:

3.1.1The flexural test

The flexural test and impact resistance test were used to investigate the mechanical polypropylene and PP/LLDPE blend. The flexural modulus of PP and PP/LLDPE blends are shown in Table 2.

Table.2. Flexural modulus of PP/LLDPE blend

LLDPE Load (wt %)	Flexural Modulus (MPa) (ASTM D790)
0	950
10	1328
20	1005
30	1257
40	755
50	629

The flexural properties of PP/LLDPE manufactured by the one-step methods are summarized in Table 2. The blending action of the LLDPE on PP in the blend was also evident in the observation depicted in Figure 1. The flexural modulus of PP was 950MPa. This figure shows the effect of LLDPE contents on modulus of rigidity of the PP. The addition of LLDPE (10, 20 and 30 wt %) to PP increased the flexural modulus to 5.8 to 39.8%. However, addition of LLDPE (40 and 50wt %) decreased the flexural modulus to 20.5 to 43.8 %, compared with PP. These observations were also in agreement with Kock, Aust, Grein, Gahleitner (2014), Clive Maier and Teresa Calafut (1998) [7],[9]. That disentanglement or rupture of tie-molecules was the dominant molecular mechanism in environmental stress cracking of polypropylene and in slow crack growth. The tie-molecules have also been identified as exhibiting similar mechanisms in impact and yield strengths. Thus, tie-molecules are important to all strength properties of polypropylene. Hence the increasing concentrations of LLDPE introduced tie-molecules into the polymer blend [7],[9].

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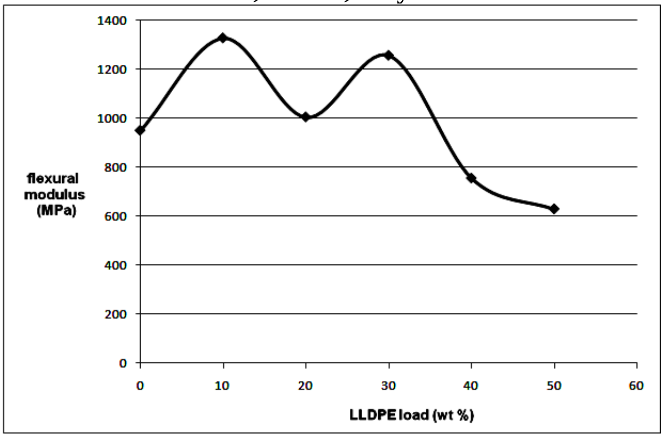

Fig.1 the Flexural modulus of PP/LLDPE blend

3.1.2 Impact test

The impact properties of PP and PP/LLDPE blends are shown in Table 3. The impact resistances of PP/LLDPE manufactured by the one-step methods are summarized in Table 3. The impact resistance of PP was 20J/m. Figure 2 shows the effect of LLDPE contents on the impact resistance of PP. The addition of LLDPE (10, 20, 30, 40 and 50 wt %) to PP clearly seen that significant increasing on the impact resistance to 23.5 to 50%. The optimum weight percentage of LLDPE on PP provides the best impact resistance is 30 wt %. These observations were also in agreement with Kock, Aust, Grein and Gahleitner (2014), Shri Kant, Dr.Urmila, Jitendra kumar, Gaurav Pundir (2013). As known the brittleness of polypropylene is related to the spherulitic morphology and the intrinsic tendency of PP for crazing followed by unstable craze growth and crack propagation under conditions of stress concentration and/or low temperatures [1]. So the impact test results indicate that the LLDPE dispersions in PP provide multiple sites for crazing and localized shear yielding as mechanisms for the impact energy dissipation [8],[10].

Table3. The Impact resistance of PP/LLDPE blends

LLDPE load (wt %)	Imact resistance (J/m) (ASTM D256)
0	20
10	26.01
20	24.69
30	30.01
40	28.44
50	27.5

From the results of the flexural and impact tests, in general, the obtained results are in good agreement with the literature such as Abu Ghalia, Mustafa A (2011) when the effects of LLDPE on the PP are considered, respectively [5]. However, the productions of such blend in the flexural and impact properties have been reported by the present study.

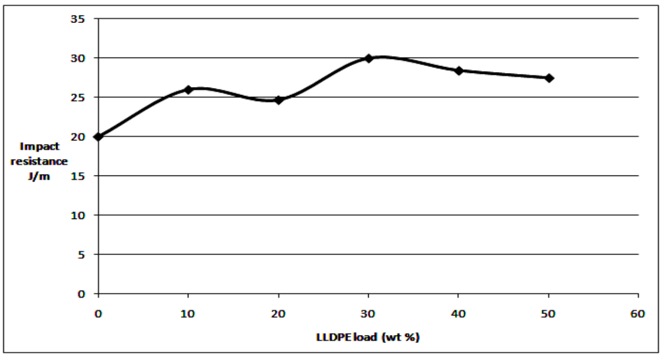

Fig 2.The Impact resistance of PP/LLDPE blend

3.2 Thermal properties

The heat deflection temperature (HDT) test is used to investigate the thermal properties of polypropylene and PP/LLDPE blend. The HDT of PP and PP/LLDPE blends are shown in Table 4. The heat deflection temperature of

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PP/LLDPE manufactured by the one-step methods are summarized in Table 4. The HDT of PP was 71oC. Figure 3 shows the effect of LLDPE contents on the HDT of PP. The addition of LLDPE (10, 20, 30, 40 and 50 wt %) to PP increased the flexural modulus to 15.8 to 68.2%. The figure 3 showed the optimum composition percentage of LLDPE on PP provides the best HDT is 30 wt %.

Table 4. The heat deflection temperature (HDT) of PP/LLDPE blend

LLDPE load (wt %)	Heat deflection temperature (HDT) (oC) (ASTM D648)
0	71
10	81.2
20	86.6
30	119.4
40	80.9
50	78.9

From the results of the heat deflection temperature test, in general, the obtained results are in good agreement with the literature such as Kristin, Juha, Matthew (2013) and Abu Ghalia, Mustafa A (2011) when the effects of LLDPE on the PP are considered, respectively [5],[11]. However, the productions of such blend in the thermal properties have been reported by the present study.

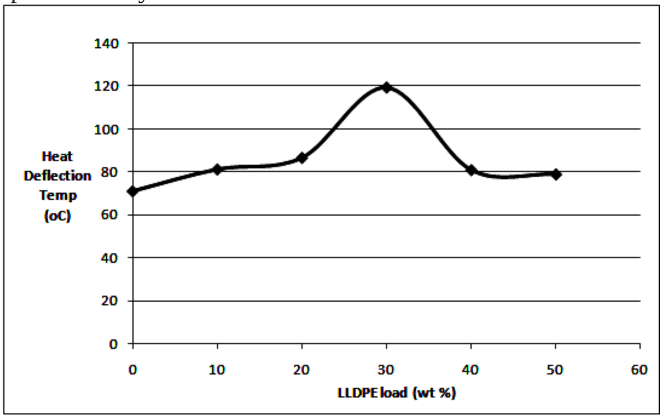

Figure 3.The heat deflection temperature (HDT) of PP/LLDPE blend

3.3 Rheological properties

The melt flow index (MFI) test is used to investigate the flow properties of polypropylene and PP/LLDPE blend. The HDT of PP and PP/LLDPE blends are shown in Table 5. The Melt flow index (MFI) of PP was 30(g/10min). Figure 4 shows the effect of LLDPE contents on the melt flow index of PP. The addition of LLDPE (10, 20, 30, 40 and 50 wt %) to PP decreased the MFI to 4.5.8 to 46.3%. The figure 4 showed the improvement on MFI of PP/LLDPE blend. The effect of LLDPE loading on the melt flow index of PP blend is shown in Figure 4. The result showed that with increasing LLDPE concentrations, the melt flow index of the composite increased. This may be attributed to the absence of branching in PP. It is reasonable perhaps, to assign the difference in melt flow properties between the PP and that of LLDPE blend to the presence of short chain branching (SCB) in LLDPE. This is because the SCB tends to increase the entanglement at low shear rate (high elasticity), but at high shear rates the chain would disentangle, thus reducing the viscosity [6].

Table5. The melt flow index (MFI) of PP/LLDPE blend

LLDPE load (wt %)	Melt flow index (MFI) (g/10min) (ASTM D1238)
0	30.87
10	29.53
20	26.13
30	23.53
40	18.93
50	16.50

From the results of the melt flow index test, in general, the obtained results are in good agreement with the literature such as Abu Ghalia, Mustafa A (2011) when the effects of LLDPE on the PP are considered, respectively [5]. However, the productions of such blend in the flow properties have been reported by the present study.

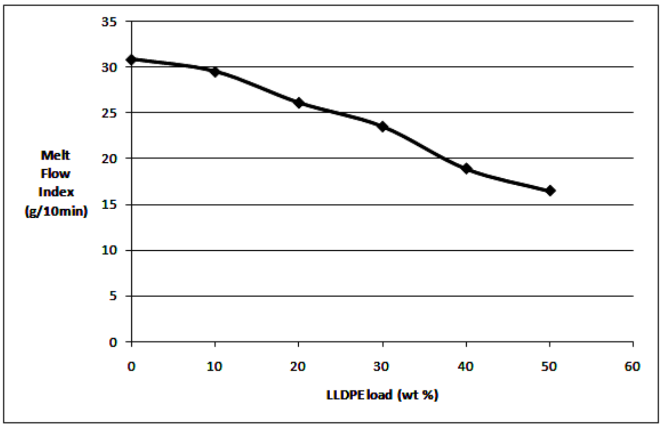

Figure4. The Melt flow index (MFI) of PP/LLDPE blend

4. Conclusion :

The addition of LLDPE to PP in most cases increased the flexural modulus to 5.8 to 39.8%, impact resistance to 23.5 to 50%. PP provides the best HDT is 30 wt %. The addition of LLDPE to PP decreased the MFI.

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