EVALUATION OF MECHANICAL PROPERTIES OF UHMWPE/LLDPE POLYMER-POLYMER BLENDS

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Abstract: To decrease the high viscosity of UHMWPE, a linear low density polyethylene (LLDPE) was added into the UHMWPE. The content of LLDPE in blends was changed from 10 to 90 wt%. The study of mechanical properties of UHMWPE/LLDPE polymer-polymer blends was the main aim of this work. Tensile strength, elongation at break, tensile yield strength, yield strength elongation, and tribological properties were measured for all blends. Tensile test results showed that the yield strength elongation is increased almost by 20% with increase in LLDPE content from 0 to 40 wt% compared to that of pure UHMWPE. On the other hand the elongation at break is increased about by 40% at 90 wt% of LLDPE in blends. It was found that UHMWPE/LLDPE polymer-polymer blends can be processed by conventional processing methods such as extrusion and compression molding in contrast to the pure UHMWPE.

1 INTRODUCTION

Extremely high molecular weight of ultrahigh molecular weight polyethylene (UHMWPE) provide a number of technically important properties including excellent wear resistance, high energy absorption capacity at high loading rates, high impact strength and cracking resistance. On the other hand, a melt viscosity of UHMWPE is extremely high due to high molecular weight. Therefore, it is not suitable for conventional processing technologies, except for high temperature compression molding and ram extrusion [1, 2].

Numerous efforts have been made to reduce the viscosity of UHMWPE by solution or gel processing [3-5]. An alternative route to reduce the melt viscosity is preparation of blends of UHMWPE with other polymers that generally have lower average molecular weights or lubricants such as stearate, PE wax, styrene, etc [6]. To improve the melt fluidity of UHMWPE, conventional polyethylenes linear low density polyethylene, low density polyethylene, high density polyethylene and polypropylene (LLDPE, LDPE, HDPE and PP) were blended with it [7–10]. Small quantities of conventional polyolefins did not improve the melt flow index of UHMWPE sufficiently to render it amenable to conventional melt processing. In this case, conventional polymers or additives are acting as plasticizers or processing aid agents. In addition, the instability and transference of these low molecular agents to the surface of the extrudate is very harmful. For this reason, the addition of low molecular weight polymer into UHMWPE does not in itself present a practical way to improve the melt processability of UHMWPE. Although some reported that the addition of a nucleating agent can counteract the bad effect of these processing aid agents, in fact, the effect is rather moderate [10].

The authors [10] have shown that UHMEPE can be extruded by a single-screw extruder by digging grooves in the extruder barrel, by devising a special screw structure to improve the mixing effect and by ultrasonic vibration to enhance processability. However, improving the processing equipment is not always easy in a practice. It was also reported [10] that mixtures of 70–90% UHMWPE and 30–10% polypropylene (PP) can be extruded by a conventional single-screw extruder, and its mechanical and tribological properties were as good as or even better than that of pure UHMWPE. However, the melt flow index of UHMWPE/PP blend is still low, for example, the melt flow index of UHMWPE/PP (75/25) was 0.66 g/10 min at 230°C and 21.6 kg load. That is, simple adding conventional polymers and agents result in decrease of some of the more desirable mechanical properties of UHMWPE, such as tensile strength, notched impact strength and wear resistance, and the detailed effects of these additives on the properties of UHMWPE need to be studied.

One more problem of such stochastic blends is large difference in melting points of mixed polymers. So, for example, for blends UHMWPE/PP and UHMWPE/LDPE these differences are approximately 30°C and 20°C respectively. It was reported that components of blends were crystallized separately from the melt. This problem does not allow homogeneous stochastic blends to be prepared by a simple mixing of components in the melt since intermolecular interaction between host polymer (UHMWPE matrix) and other low molecular weight polymers (additives) is very weak. To improve the interphase bonding between UHMWPE and other polymers, a suitable compatibilizer, polyethylene-*graft*-maleic anhydrite (PE-*g*-MAH), is frequently employed [11-13].

It was found [11] that without compatibilizer, UHMWPE and polyurethane (PU) were immiscible polymers and adding PE-*g*-MAH reduced the size of the dispersed PU domains by a factor of 10 to reach 0.5–5 μm and caused a more uniform distribution of the PU phase in the UHMWPE matrix. Also, PE-*g*-MAH influenced the crystallinity of UHMWPE, increased the amorphous region in the UHMWPE phase, and improved interfacial adhesion.

The same result was reported for UHMWPE/liquid crystalline polymer composites (coded as UHMWPE/LCP) compatibilized with PE-*g*-MAH [12]. The effect of the compatibilizer on the mechanical, thermal, and tribological properties of the UHMWPE/LCP composites was investigated. It was found that the incorporation of the PE-*g*-MAH contributed to decrease the melting points of the composites and decrease their crystallinity to some extent. Moreover, the inclusion of the PE-*g*-MAH compatibilizer helped to greatly increase the tensile rupture strength and tensile modulus of the composites, which was beneficial to improving the wear resistance. Such improvements in the tensile and tribological behavior of the UHMWPE matrix composites by the PE-g-MAH compatibilizer could be closely related to the enhanced cross-linking function of the composites in the presence of the compatibilizer.

In this work we are using other effective method for enhancing the interphase interaction between UHMWPE and LLDPE, namely, the method of high-energy mechanical activation in a planetary ball mill. This method is well-known and it is widely applied in processing technologies of metals, ceramics and polymeric materials [14]. Processes that can be observed in polymeric composites during high-energy activation in planetary ball mill are as follows:
– graft of additives or processing aid agents to a polymeric matrix and formation of new chemical bonds;
– formation of side radicals;
– formation of volume grids;
– change of a sub-molecular structure; etc.

In general, these processes can result in increase of interaction between a polymeric matrix and additives or processing aid agents, and in a more uniform distribution of their in a matrix, and finally, to improvement of mechanical characteristics of polymeric compositions.

The study of mechanical, thermal and tribological properties of composites UHMWPE/LLDPE was the main aim of this work.

2 EXPERIMENTAL PROCEDURE AND SAMPLES

UHMWPE powder (GUR 4120, Ticona, Germany) was used for samples preparation by the high temperature compression molding. The average molecular weight of UHMWPE is about $5{\cdot}10^6$ g/mol. Powder of LLDPE (Hanwha 3305, Korea) was used as an additive or plasticizer for blends UHMWPE/LLDPE. Powder of LLDPE-*g*-SMA (Olenta, Russia) was used as a compatibilizer for blends UHMWPE/LLDPE. The content of LLDPE-*g*-SMA was 3 wt% for all blends. The content of LLDPE in blends studied was changed from 7 to 87 wt%, and the total ratio UHMWPE: (LLDPE+LLDPE-g-SMA) for blends was changed from 90:10 to 10:90. Dry mixes of all blends were prepared by the planetary ball mill for 15 min. Samples of all blends UHMWPE/(LLDPE+LLDPE-*g*-SMA) were prepared by the hot pressing in special compression molds. Compression molds filled with dry mix of UHMWPE/(LLDPE+LLDPE-*g*-SMA) were placed into a vacuum oven heated up to 170°C for 3 h. After that, compression molds were pressed in a hydraulic press at 12 MPa for 20 min. Compression molds were slowly cooled at the cooling rate of 4°C/min up to ambient temperature under pressure in air. Samples were prepared as rectangular plates 100×50×1 mm. Plates were cut into samples with dumbbell shape for the mechanical tests. Samples for tribological measurements were prepared as discs with diameter 15 mm and thickness of 5 mm.

The mechanical properties such as yield strength, elongation at yield strength, tensile strength, and elongation at break were measured by a universal testing machine Instron 5582. All samples were tested at tensile rate of 1 mm/min. Not less than 10 samples were measured for each blend.

Temperatures and temperature intervals of melting and decomposition of blends, the heat flow and a weight loss of samples were measured in the temperature range from 25 to 500°C at a heating rate of 10°C/min in an argon atmosphere by means of a combined DSC-DTA-TGA analyzer Q600 “TA Instruments”. From three to five samples of each composite were tested for all test conditions.

Measurements of the friction coefficient and wear rate were carried out by high temperature tribometer THT-S-AX0000 and micro measure 3D station profilometer. A pin-on-disc tribometer consists of a stationary pin under an applied load in contact with a rotating sample (Figure 1).

The pin had a shape of ball with diameter of 6 mm. Loading force on the pin L_n was 5H, and a linear rotation velocity of the sample was 5 cm/s at 20°C.

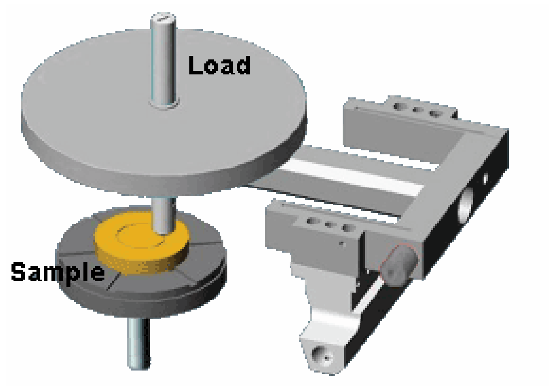


Figure 1: Pin-on-disk type tribometer schematic diagram

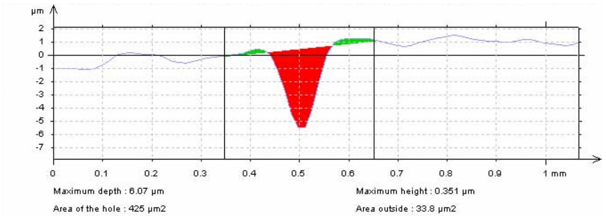


Figure 2: Definition of profile and area of wear track by the 3D profilometer

The wear rate was measured by a contactless 3D profilometer as a specific area of the wear track $S_w = S/L$, where S is the area of the wear track (Figure 2), and L is a sliding distance. The sliding distance was L = 110 m for all blends. Five samples were tested for each blend.

3 EXPERIMENTAL RESULTS AND DISCUSSION

All results of mechanical tests were represented as stress-strain curves. Typical stress-strain curve for blend with ratio of UHMWPE/(LLDPE+LLDPE-*g*-SMA) 60:40 is presented in Figure 3.

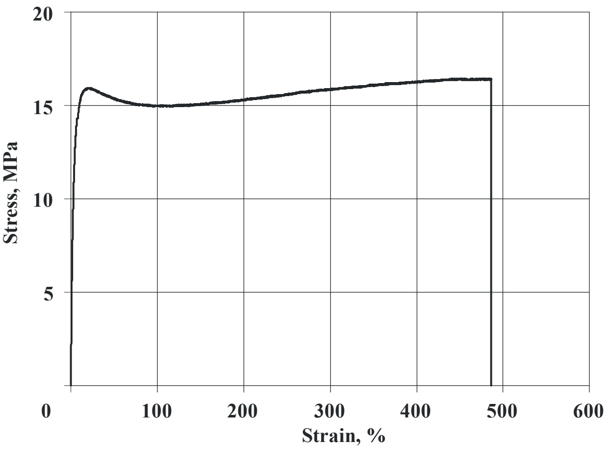
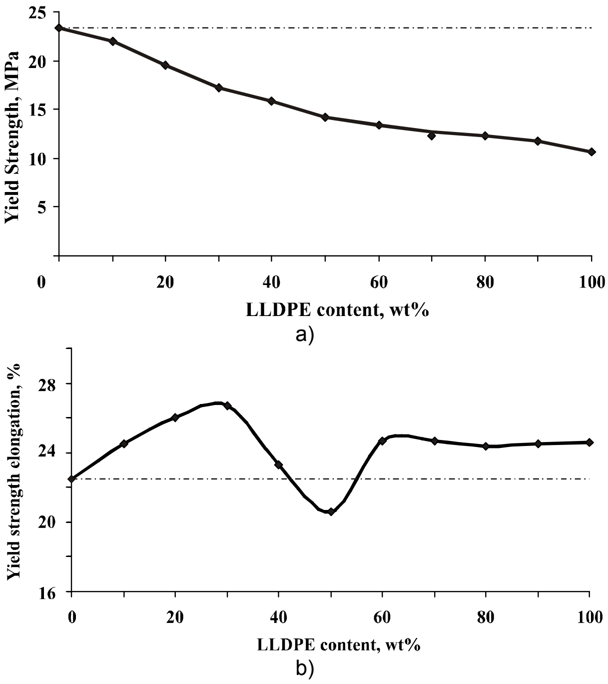


Figure 3: Typical stress-strain curve for blend with ratio of UHMWPE/(LLDPE+LLDPE-*g*-SMA) 60:40

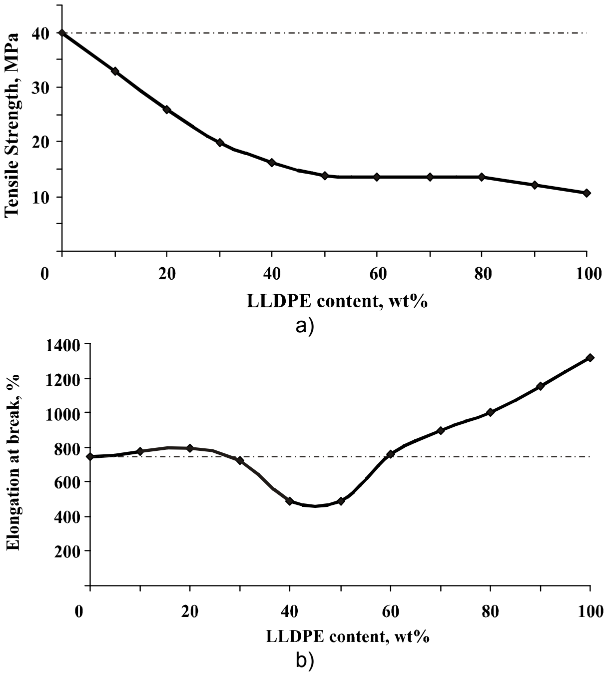
The same results were obtained for all samples. Average values of yield stress, elongation at yield stress, tensile strength, and elongation at break were calculated from these data for all blends. Summarized results of mechanical tests are shown in Figures 4 and 5. It is obvious that both yield strength and tensile strength are decreased by factors of 2 and 3.3 respectively with increase in LLDPE content from 10 to 90 wt% compared to those of pure UHMWPE (dashed line).



a)

b)

Figure 4: Yield strength (a) and elongation at yield strength (b) for blends UHMWPE/LLDPE



a)

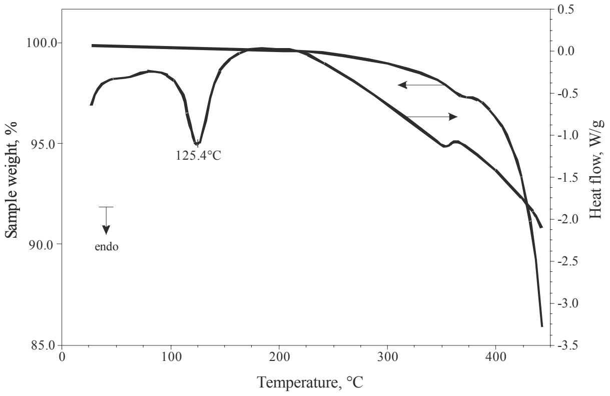
b)

Figure 5: Tensile strength (a) and elongation at break (b) for blends UHMWPE/LLDPE

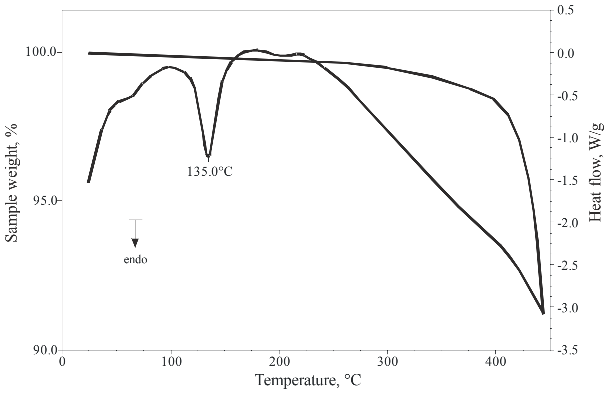
The elongation at yield strength is improved for all blends compared to that of pure UHMWPE, except the blend with ratio 50:50. The elongation at break has the minimum for blends with ratios 60:40 and 50:50, and it is increased by about 50 % for blend 10:90 compared to that of pure UHMWPE. When

LLDPE content does not exceed 30 wt% the elongation at yield strength of UHMWPE/LLDPE blends grows by ~20 % compared to those for pure UHMWPE. On the other hand the elongation at break is slightly increased with increasing LLDPE content up to 30 wt%. Generally speaking, the increase of the elongation at yield strength and the elongation at break with increase of the LLDPE content in blends is reasonable due to the higher elongation of LLDPE, but the decrease of them at 40–50 wt% of LLDPE is a strange occurrence and we can not explain this experimental fact.

Results of DSC/TGA analysis are shown in Figure 6. It can be seen that the melting point is increased for UHMWPE/(LLDPE+LLDPE-*g*-SMA) 90:10 and 60:40 by 10°C and 7°C respectively compared to that of pure UHMWPE. The further increase in LLDPE content up to 50 wt% results in decrease of the melting point of blends. This fact testifies that the interphase interaction is increased for ratios UHMWPE/LLDPE from 90:10 to 60:40, and it can result in the increase of both the elongation at yield strength and elongation at break. Thermal stability of blends with ratios UHMWPE/LLDPE 90:10 and 60:40 also increased. So, the sample weight lost for blends with ratios UHMWPE/LLDPE 90:10 and 60:40 is 6.4 % and 5.9 % while for pure UHMWPE it is 11.2 % at the temperature 475°C. That is, blends with ratios 90:10 and 60:40 have higher decomposition temperature.



a)



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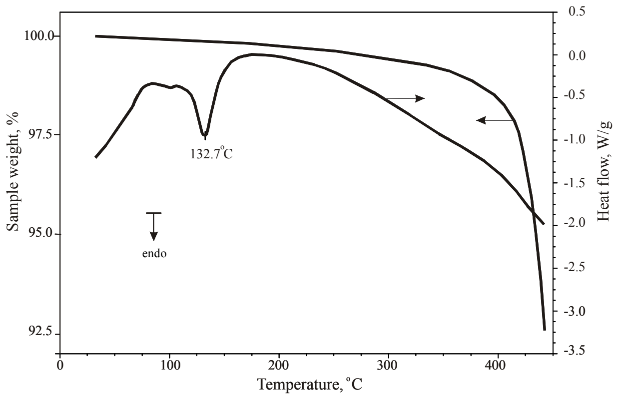
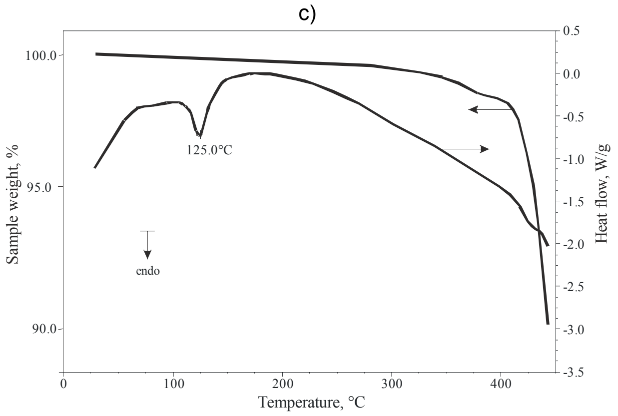


c)



d)

Figure 6: DSC/TGA thermograms for pure UHMWPE (a) and UHMWPE/(LLDPE+LLDPE-*g*-SMA) blends: 90:10 (b), 60:40 (c), and 50:50 (d)

The coefficient of friction μ can be calculated as the quotient of the friction force F_s and loading force F_n coming from the constant load. The comparison of values of μ for all blends was carried out at the same sliding distance 100 m. The results of this study are shown in Figure 7.

The coefficient of friction is initially curvilinear and the rate of volume loss per unit sliding distance in the transient wear regime decreases until it has reached a constant value in the steady-state wear regime. It can be seen that the coefficient of friction is increased for all blends compared to pure UHMWPE by 1.8–2.9 times with increase in LLDPE content from 20 to 80 wt%. However in spite of increase in the value of μ it is lower in comparison with pure LLDPE. For instance, the value of μ for the blend UHMWPE/LLDPE 80:20 is decreased twice compared to that for pure LLDPE. That is, these blends can be used as materials with higher wear resistance.

4 CONCLUSIONS

1. UHMWPE/LLDPE blends modified by small quantities of LLDPE-*g*-SMA compatibilizer in a planetary ball mill possess the higher thermal characteristics compared to both LLDPE and UHMWPE. That is, the energy of interphase interaction in these blends is higher compared to that of untreated UHMWPE/LLDPE blends.

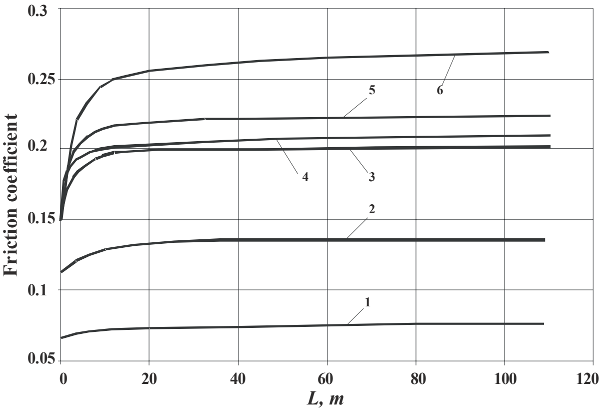


Figure 7: Friction coefficient for: 1, UHMWPE; 2, 80:20; 3, 40:60; 4, 30:70; 5, 20:80; and 6, LLDPE

2 Both the elongation at yield strength and elongation at break are increased at low LLDPE content. The coefficient of friction for such mixes is almost twice below, in comparison with that of pure LLDPE.

3 Modifying UHMWPE by small quantities of LLDPE allows UHMWPE/LLDPE blends suitable for the injection molding and extrusion to be prepared without improvement of the conventional processing equipment.

5 ACKNOWLEDGMENTS

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