Comparison of different properties of high-density polyethylene (HDPE) grades with high melt flow index for use in the production of masterbatch and injection of thin-walled parts

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Abstract

In this paper, the various physical, mechanical, thermal and rheological properties of two different grade of HDPE for use in the process of injection of thin-walled parts and also the preparation of high filler loading masterbatches, have been compared. These two grades have a melt flow rate (2.16 kg) greater than 16 g/10min. Tensile and impact tests have been used to study mechanical properties. Differential Scanning Calorimetry (DSC) and re-extrusion tests were performed to evaluate the thermal properties of these grades. In order to study the rheological properties of these products, capillary rheometry and oscillating rheometry tests have been done on these two grades. Finally, the advantages and disadvantages of these two grades are compared.

Introduction

Injection molding refers to the process of manufacturing plastic injectable products based on thermoplastics and thermosets materials. In today's world, almost nothing can be done without using injection molded parts. This process is used to produce various products such as pallets, kitchen utensils, food containers, boxes, toys, disposable containers, thin-walled kitchen utensils, etc.

In this process, the materials after mixing in a hot extruder are injected into the mold cavity (where the molded part is cold and hard). Most polymers, including all thermoplastics, some thermosets, as well as a number of elastomers, can be used in injection molding. Common polymers such as epoxy resin and phenolic resin are two examples of thermosets and nylon, polyester and polyolefins are examples of thermoplastics (1).

Today, in order to reduce production costs, save on consumables, increase production speed (shortening the injection cycle time) and increase demand for more lightweight packaging with higher strength, the production of thin-walled parts has been considered. Thin wall parts are referred to the pieces having a wall thickness of less than 800 microns. Of course, this amount is increased by 2 mm for large parts of the car, and in general, the meaning of the thin-walled is dependent on the size of the piece. The process of manufacturing these parts varies with previous injectable parts and requiring higher pressure, higher cooling speed, faster molding, and optimization of runners and ejectors. In general, in each piece, by reducing the thickness of the product walls, the process becomes more difficult by the injection method. In the production of thin-walled parts, materials should be injected into the mold at high speed to prevent premature freezing of materials in the mold before filling the mold completely. The technology and new materials in the production of these parts are focused on filling the mold faster and easier. In the type of thin-walled molding, due to the narrow path of the flow, the flow resistance is high and by increasing the mold and melt temperature, reducing the viscosity of the melt, increasing the injection pressure and also increasing the injection speed, this flow resistance can be reduced. For the above reasons, in this method, the injection speed is high and is about 6 to 20 seconds, while in the old methods; this time is between 40 and 60 seconds. High-speed injection devices, robotic systems, special molds, precise design and special materials for injection of thin-walled parts are needed in this regard. As a result, one of the uses of polymers with a high melt flow index is the production of thin-walled injection molded parts (2).

On the other hand, in order to make masterbatches and compounds with high-percentage filler, it is necessary to use high melt flow polymer as the matrix to facilitate the production process and prevent excessive pressure on the production apparatus.

HDPE is produced from polymerization of ethylene at low pressure and temperature, compared with the production of low-density polyethylene production. This polymer is free from the long chain branch and metallocene or Ziegler-Natta catalysts can be used in the production of this grade. HDPE can be up to 95% crystalline. This higher crystallization rate leads to increased density, modulus, tensile strength, heat deflection temperature, chemical resistance and resistance to gas penetration compared to low-density polyethylene. In contrast, the impact strength in this polymer has been decreased, which increases with the increment of the molecular weight of this polymer. The fatigue strength of this polymer is high but not as much as polypropylene, but in comparison with homo-polypropylene, it has better properties in terms of impact resistance at low temperature and oxidation resistance. Environmental Stress Crack Resistance (ESCR) of this polymer is low. When producing this product, the final properties are controlled by density, molecular weight, and molecular weight distribution.

This polymer is one of the main materials used in the injection process, and in particular the injection of thin-walled parts, as well as the preparation of various types of compounds and masterbatches.

In general, the properties of polyolefin injection parts are (2, 3):

• Lightweight

• Excellent chemical resistance

• Low-temperature toughness

• Excellent dielectric properties

• No dependence on moisture

In this paper, the comparisons of different properties of two different grades with high melt flow index have been compared and the advantages and disadvantages of these two have been compared.

Experimental

Two different types of HDPE commercial grades from Jam and Tabriz petrochemicals have been used in this work. The grade from Jam Petrochemicals, titled HD-1, and the grade from Tabriz petrochemicals, titled HD-2. The HD-1 has a melt flow index of about 18 g/10 min at a weight of 2.16 kg and HD-2 with an MFI of about 20 g/10 min. The density of HD-1 and HD-2 were 0.952 g/cm^3 and 0.956 g/cm^3 respectively. To measure mechanical properties, tensile tests with the tensile rate of 50 mm/min based on ASTM-D 638 and impact test based on the Izod method were utilized. In order to study the thermal properties, DSC test was conducted from the ambient temperature to 190 ° C at a speed of 10 ° per minute by the Mettler Toledo DSC822 apparatus manufactured by the United States. In order to investigate the processability and also the degradation of the samples, the melt flow index test at 190 ° C and in the weights of 2.16 kg was performed by the CEAST MFM multiweight machine made in Italy. Capillary rheometry test was performed by Gottfert machine model Rheograph 25 made in Germany in order to study the rheometric behavior of the samples and also to investigate the occurrence of melt phenomena at 180 ° C and 14 points. To study the rheology of samples in an oscillating state, oscillatory rheometry test was carried out at a temperature of 190 ° C and swept at a frequency from 0.05 to 600 Hz and in the range of 1% strain to ensure linear positioning, by Anton Paar MCR 502 Made in Austria.

Results and Discussions

Mechanical properties

The results of the tensile test as well as the impact test are presented in the following table. The samples for these tests were prepared in two methods: hot pressing and injection molding.

Table 1- Results of tensile and impact tests for the samples

	standard	unit	HD1-Hot press	HD2- Hot press	HD1-injection molding	HD2-injection molding
Impact	ASTM D-256-A	j/m	25.8	26.6	39.23	40.24
Tensile strength @ yield	ASTM D-638	MPa	-	32	22.6	25.4
Tensile strength @ break	ASTM D-638	MPa	27.8	26.8	11.8	12.1
Elongation @ yield	ASTM D-638	%	-	7.3	11	9.2
Elongation @ break	ASTM D-638	%	5.7	15.9	184	288

As can be seen, the results of the two methods of preparation of samples are very different, which indicates the effect of the different method of preparing the specimens. In the samples prepared by the hot pressing method, the tensile strength increased, while the elongation at break is much less than the samples prepared by the injection method. This can be due to the difference in the cooling rate of the samples. In samples prepared by the hot pressing method, the cooling rate is 4 degrees per minute, which results in increased crystallinity, but in injection samples, the cooling rate is high and the crystallinity decreases.

As a result, the samples obtained from the hot pressing are stronger (higher tensile strength) and have a lesser elongation at break compared with the samples made with an injection molding method.

According to studies, with increasing density, the tensile strength at yield and break increases, which is visible in sample results. On the other hand, increasing molecular weight or decreasing the melt flow index leads to increased elongation at break and tensile strength at break. Comparing the samples, the effect of decreasing the melt flow index on tensile strength at break is evident and at this point, the effects of reducing the density, as well as the effect of the molecular weight increment are in contrast. Of course, in studying the elongation at break, the molecular weight increment and density decrement lead to an increase in the elongation at break and also increase the resistance to impact, which in this case, the opposite happened. This can be due to differences in the production method and the different structure of these two samples. As a result, the mechanical properties of the HD-2 sample are better than another one.

Thermal properties

The results of the DSC test are presented in the following table.

Table 2- results of the DSC test

sample	Vicat °C	Melting point °C	Crystallisation point °C	Crystallinity Percent %
HD-1	122	129.2	116.10	61.1
HD-2	124	130.1	117.25	62.3

Basically, the factors that increase the percentage of crystallinity, these factors also increase the size of the crystals. The increment of the size of the crystals will result in an increase in melting temperature. Comparing the results, the sample with higher density and crystallinity percent (HD-2) has a higher melting point and crystallization temperature. In the case Vicat point, these same factors are involved so the only effective parameter is density, and with increasing density of the sample, the Vicat point of the sample also increases. Of course, these differences are negligible and these two samples are very close in terms of the thermal properties.

In order to investigate the resistance of these specimens against degradation, the re-extrusion test was performed on the samples and at each stage, their melt flow index was measured at a weight of 2.16 kg. The results of this test are presented in the table below.

Table 3- Results of re-extrusion test

samples	unit	MFI_0	MFI_1	MFI_2	MFI_3
HD-1	g/10 min	16.4	17.44	17.82	19.2
HD-2	g/10 min	20.35	22.2	24.24	24.55

According to the results, with the increasing number of extrusion processes, the melt flow index has increased in both samples, indicating the degradation of polymer chains. But among the two samples, the HD-1 has shown a lower degradation, which indicates better properties of the sample for recycling and can be used for many times. Of course, it should be noted that by increasing degradation in these specimens processability will improve.

Rheological properties

Figure 1 shows the results of the oscillatory rheometry test for these two samples.

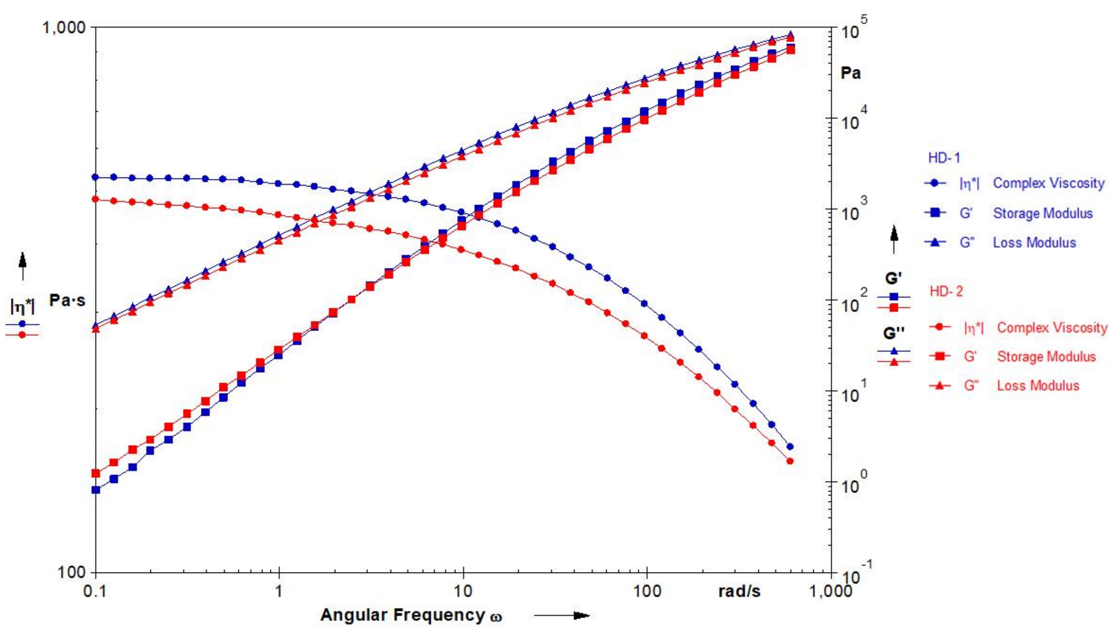

Figure 1: The results of the oscillatory rheometry test for the samples

Figure 2 shows the results of the capillary rheometry test for these two samples.

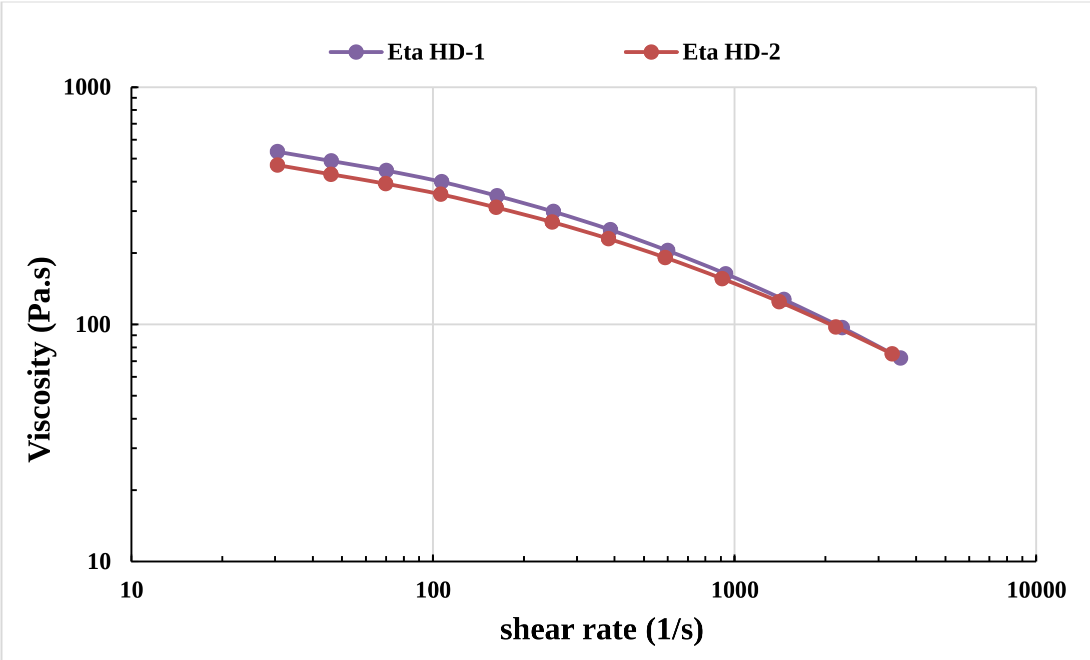

Figure 2: The results of the capillary rheometry test for the samples

Regarding figures 1 and 2, as expected, the HD-1 sample has a higher viscosity and less processability than HD-2. Of course, at the high shear rates, the behavior of the two samples is similar to each other so in terms of processability, in processes with very high shear intensity, there are no differences between them. Another noteworthy point is that in both of these samples, no melt fracture has occurred in any of the shear rates, which suggests that both of these samples can be easily used in high shear intensities.

Conclusion

In this paper, we compared the various physical, mechanical, thermal and rheological properties of two different grades HDPE for use in the process of injection of thin-walled parts and also the preparation of high filler loaded masterbatches. These two grades had a melt flow index greater than 16 g / 10min at a weight of 2.16 kg. Tensile and impact tests have been used to study mechanical properties. DSC and re-extrusion tests were performed to measure the thermal properties of these HDPEs. In order to study the rheological properties of these products, capillary rheometry and oscillatory rheometry tests have been conducted on them. The study of mechanical properties showed that the HD-2 sample exhibited better mechanical properties compared to the HD-1 grade. The thermal test results show that these two specimens have very close thermal properties the melting temperature of the HD-2 sample is slightly higher than HD-1and in terms of degradation, the HD-1 specimen has better degradation properties and the degradation has occurred at a lower rate. Rheological properties indicate better processability of HD-2, but both of these samples have good processability, and there are no melt fracture phenomena even in high shear rates. Finally, it can be said that both of these samples are ideal grades for use in the production of thin-walled injection molded parts and a high filler loaded masterbatches.

References

1- John Goff, (2013), **Injection Molding of Thermoplastic Materials – 2**, Springer Science & Business Media, Berlin, Germany.
2- Musa Rasim Kamal, Avraam I. Isayev, Shih-Jung Liu, (2009), **Injection Molding: Technology and Fundamentals**, Carl Hanser Verlag, Munich, Germany.
3- Dennis B. Malpass, (2010), **Introduction to Industrial Polyethylene: Properties, Catalysts, and Processes**, John Wiley & Sons, Hoboken, New Jersey, United States.