The influence of HDPE recycling on rheological properties and processing conditions

Pavel Oblak, Alexandra Aulova, Marko Bek, Lidija Slemenik Perše

University of Ljubljana, Faculty for Mechanical Engineering, Laboratory of Experimental Mechanics, Ljubljana, Slovenia

ABSTRACT

According to the latest analysis of European plastics production performed by Plastics Europe[1], High Density Polyethylene (HDPE) together with Medium Density Polyethylene were on the third place among the most demanded plastics in Europe in 2016. Mostly used for manufacturing of packaging HDPE gained its demand due to superior mechanical properties, resistance to external impacts and ease of processing.

More than 6 million tons of HDPE products were produced in 2016, which creates the problem of recycling extremely relevant. Within this paper we investigate how the addition of recycled material during processing affects the processing conditions during extrusion.

INTRODUCTION

Only in Europe tens of million tons[1] of the polymer resins are turned into products and released to the market every year. Such quantities of the plastic products, mainly made of non-biodegradable materials, such as HDPE, represent vast danger to the environment and recycling is therefore necessary in order to reduce the high rates of plastic pollution.

During the last 10 years, the significant increase of plastic recycling and energy recovery was induced in European countries[1]: from 2006 till 2016 plastic recycling increased for 79%, energy recovery increased for 61%, while landfill amount decreased for 43%. In 2016 for the first time in history more plastic waste was recycled than refilled, which indicates positive trends and relevance of recycling methods.

Recycling of the material is the most relevant for packaging products, which have relatively short life cycle. It is done typically by grinding of the used recycled product and adding of the obtained material to the raw polymer while producing new products. As it has been shown by large number of researchers, including our research group[2,3], the recycling, especially when performed multiple times, significantly changes mechanical properties of the final product and requires adjustment of the processing conditions.

Within this paper we considered how the amount of recycled material, especially when recycled many times, affects the extrusion process, namely the screw torque and the melt pressure in the die. Special attention was given to the flow of the material from the die and die swelling effects.

EXPERIMENTAL

Within the previous work[2,3], processability, mechanical and rheological properties of extensively mechanically recycled HDPE were investigated. Mechanical recycling was simulated by one-hundred consecutive extrusions. After each cycle, a portion of the material was removed and later characterized. This work represents the extension of former research and is

oriented towards investigating the effect of an addition of a recycled material to a raw material, as it usually happens in the production.

Raw material

As a raw material, LANUFENE®HDI-6507UV, produced by Ras Lanuf Oil & Gas Processing Co. was used. According to the producer this product is a very high-density polyethylene resin for injection moulding of products with high mechanical properties and good processability as the main characteristics. Producer further emphasizes suitability of material for the manufacturing of crates, containers, trays and other similar injection moulded objectives where good weather-ability and mechanical properties are needed. In addition, the material contains UV light stabilizers and recommended processing temperature is 220 – 270 °C.

Recycled material

As the base for the preparation of recycled extrudates, the raw material, presented in the previous subsection, was used. The recycling was mimicked by 100 cycles of consecutive extrusion. The details on the procedure are presented elsewhere[3]. Within this study extrudates recycled 1, 2, 5, 10, 20, 30, 40, 50, 60, 70, 80, 80, 90 and 100 times were added to the raw material in different quantities (10, 30, 50, 70 and 90%).

Material processing

For the purpose of material mixing, a twin-screw extruder, PolyLab PTW 16/40 OS, produced by Thermo Scientific (Germany) was used (see detail (a) in Fig. 1). In the extruder a horizontal rod die (type 557 - 3235) and a nozzle with diameter of 4 mm were inserted ((b) in Fig. 1).

Material was extruded at screw rotation of 150 min^{-1}, and processing temperature of 240 °C with a throughput between 1200 and 1300 g/h. After the material was extruded, it was firstly transported by the conveyor ((c) in Fig. 1) and further, to increase cooling time, also by the wheel supports ((d) in Fig. 1). Afterwards, the extrudate was pelletized using a Thermo Haake pelletizer (type 557-2685; see (e) in Fig. 1).

Recorded parameters

PolyLab PTW extruder, used for mixing the materials, allows monitoring and recording the screw torque, M(t), as well as the pressure of the melt, p(t), in the die channel (see Fig. 2). The screw torque was measured by a built-in torque sensor (type 567-0100) while melt pressure was recorded by pressure gauge (type 557-2571) installed in the die.

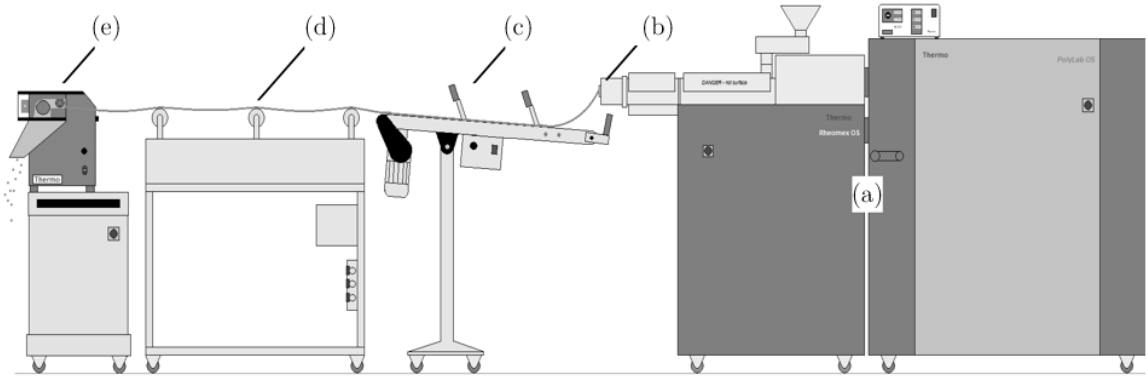

Figure 1: Configuration of the equipment during the extrusion.

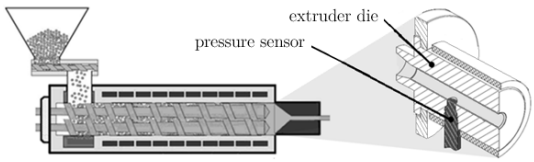

Figure 2: Scheme of twin screw extruder with the position of the pressure sensor.

It is necessary to emphasize that during the complete extrusion – mixing all the combinations, set processing conditions, i.e. barrel temperature, screw speed and material throughput, remained unchanged. Real time melt pressure and extrusion torque were recorded at every extrusion cycle and averaged over 10 min with the data acquisition sampling rate of 10 data points/minute.

RESULTS

Figs. 3 and 4 demonstrate the dependence of the extruder screw torque and the pressure in the die, respectively. As visible from both Figs. the amount of added recycled material increases both parameters for all the recycled materials added. Number of recyclations to which the added material was previously subjected on contrary has a non-linear effect. Between the 20th and 30th cycles of consecutive extrusions the material properties change to such an extent that it causes a jump in both measured parameters. With further increase on recyclation number the recorded processing parameters gradually decrease.

The observed behavior is supported by findings from our previous research[3] that was focusing only on mechanical recycling of the material without mixing it with the raw HDPE, which indicated that through the first 30 extrusion cycles the molecular structure is being dominated by chain branching, while after 30th extrusion cycle chain scission becomes predominant over the chain branching. After 60th extrusion cycle, the branched molecule chains begin to cross-link. This effect becomes more pronounced with increasing number of extrusions, but up to 100th extrusion cycle it is still being dominated by the chain scission, even though almost a quarter of the material has been cross-linked.

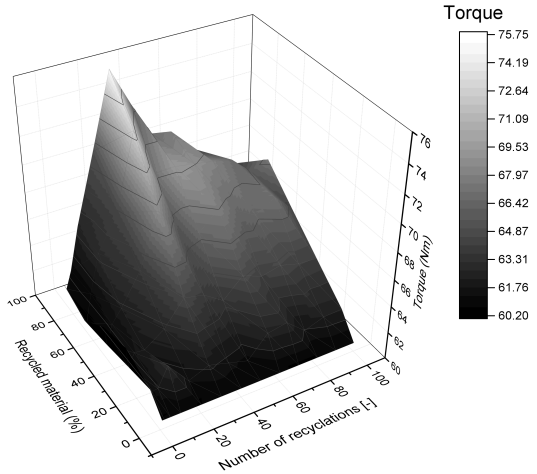

Figure 3: Dependence of the extruder screw torque on the number of recyclations and portion of recycled material.

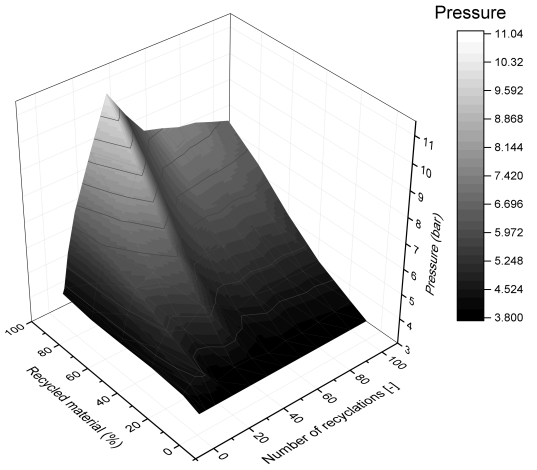

Figure 4: Dependence of the pressure in the die on the number of recyclations and portion of recycled material.

Figs. 5 and 6 demonstrate the behavior of the mixed material on the exit of extruder die. In Fig. 5 die swelling effect is presented and Fig. 6 shows the behavior of the extrudate at the cooling stage.

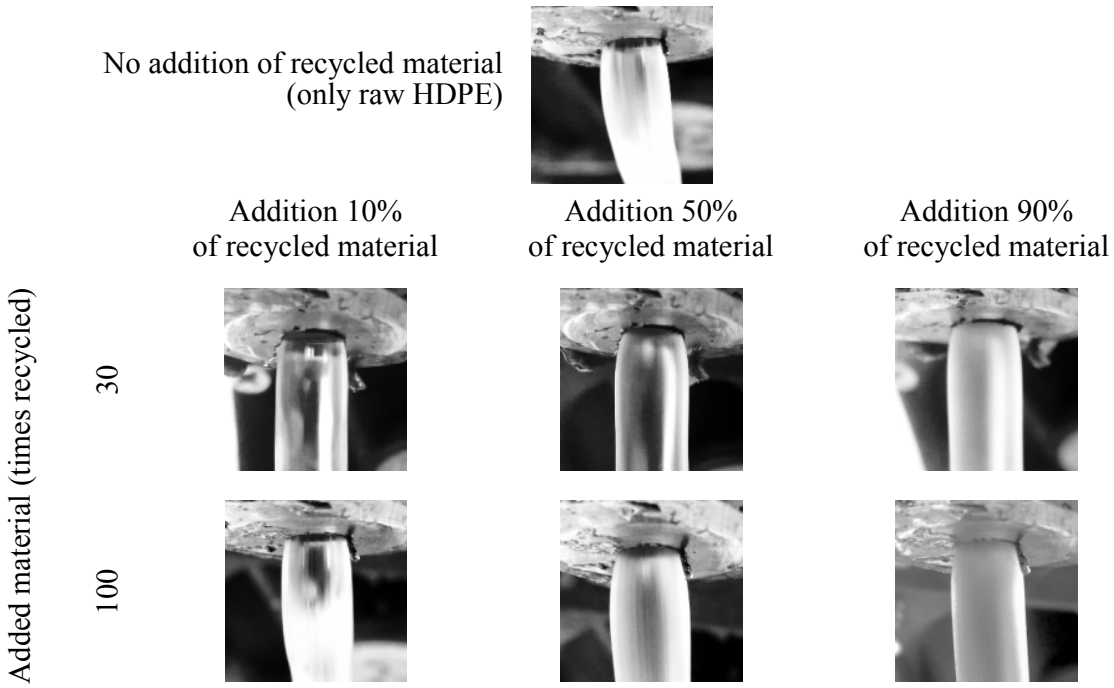

Figure 5: The die swell behaviour at the extrusion process.

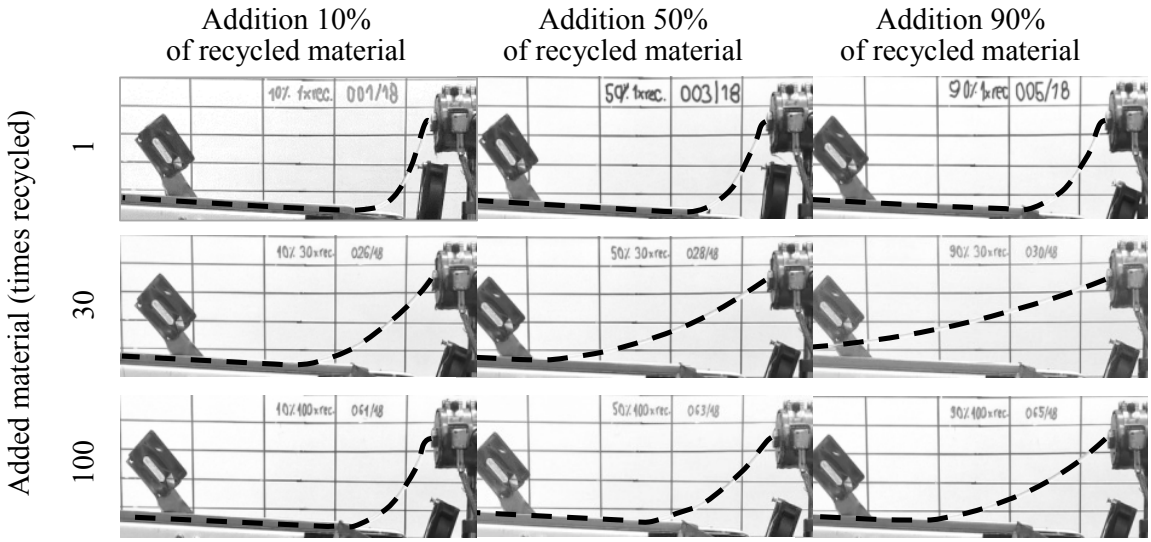

Figure 6: The behaviour of the extrudate in a cooling stage.

Analysis of Figs. 5 and 6 allows one to conclude that die swell effect was not prominent when extruding the raw material, neither became pronounced with addition of recycled HDPE material in any concentration. Contrary, the addition of the recycled material affected the behaviour of the extrudate in a cooling stage. The greatest

changes were noticed when the extrudate of 30 times extruded material was added to a row one.

CONCLUSIONS

Within the presented investigation, the effect of an addition of recycled HDPE to processing conditions during extrusion was studied. Results on recorded processing conditions, i.e. processing pressure and torque, showed unfavourable effect of added recycled material. Addition of recycled material increased both parameter, while the effect was the most significant when adding the material recycled 30 times. Besides processing condition, attention was given also to the potential die swell effect and to the flow of the extrudate during the cooling stage. Die swell effect was not prominent when extruding the raw material, neither became pronounced with an addition of recycled HDPE. On the other hand, the addition of recycled material influenced the behaviour of the extrudate in the cooling stage. It can be concluded that the addition of recycled material affects the structure of an extrudate and consequently its rheological properties.

AKNOWLEDGEMENTS

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