Chapter 207

Effect of rotation of torque rheometer rotors on HDPE/ UHMWPE blend mixture

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ABSTRACT
Seeking to evaluate the quality of polymeric blends when subjected to shear and temperature, the importance of the Torque Rheometer (RT) for the adjustment of process parameters is highlighted. That's because the Torque Rheometer (RT) is a state-of-the-art mixing and measuring system that focuses on specific research and development needs using small quantities of the sample (50g). The blends of high-density polyethylene (HDPE) and ultra-high molecular weight polyethylene (PEUAMM) were mixed at concentrations of 100/0, 90/10, and 70/30, all containing 0.5g or 1% of Irganox Antioxidant. The results were obtained from curves of torque as a function of time, which made it possible to evaluate the degradation of the blends during mixing, as well as the time to establish a homogeneous mixture. From the results obtained, it was observed that the blend of HDPE with 30% of PEUAMM composition in the rotation of 50 RPM presented a maximum torque as a function of time, being smaller than that of the blend of 10% of PEUAMM with the same rotation. The decrease in torque may have been due to molecular orientation since in the melt homogenization region (represented by the minimum torque) an increase in torque was observed over time. The addition of the thermal stabilizer may have avoided the thermal degradation of the 30% blend of PEUAMM for the 50 RPM rotation. Therefore, the mixing of HDPE/PEUAMM blends occurred without thermal degradation and with an indication of more difficult processability due to the increase in torque during the homogenization of the melt, with greater energy expenditure.

Keywords: Torque rheometer, HDPE, PEUAMM.

1 INTRODUCTION

Polymers have received special attention in the scientific area and general communities of polymeric materials processing. With mixing, it is possible that new materials can adapt to different applications. A huge range of materials can be added, there are dyes, filler materials, and even the fibers are mixed with various polymers [1].

High-density polyethylene (HDPE) has good mechanical properties and easy manufacturing characteristics and is used in several industrial applications, being considered one of the most important and durable polyethylenes. Due to its durability and physical and chemical resistance, HDPE is durable and can be converted into pipes, hoses, and even fuel tanks. HDPE has advantages over other polyethylenes because it allows for more uses and applications. It is formed by little branched molecules and has few flaws and this determines its linearity. A relatively low level of defects (which prevent organization) results in a high degree of crystallinity, which generates resins with high density compared to other types of polyethylene [2,3].

Ultra-high molecular weight polyethylene (UMMWPE) is considered an engineering polymer due to its excellent mechanical properties, excellent toughness, and low density, which makes it a general-purpose material, and its interest in the industry is growing.

In PEUAMM, the polymer chains are much longer than in polyethylene (PE). This ensures that certain material properties (PEUAMM) are better than other types of PE, such as high abrasion resistance, high chemical resistance, good mechanical properties, and flexibility, and it is sometimes referred to as engineering plastic [4].

Good properties such as abrasion resistance, high chemical resistance, good mechanical property, and flexibility, can ensure that PEUAMM can be used in various fields, mainly because it is not suitable for other types of polymers due to its characteristics. In addition, PEUAMM has biocompatibility and other properties and can be used as a prosthesis and other surgical instruments [5].

The Haake equipment is a mixing system, as well as an extrusion system (when a cylinder containing one or two threads is coupled to it), thus being used to carry out cutting-edge measurements. It focuses on specific research and development needs, providing material data relevant to the process, including melting behavior, the influence of additives, temperature stability, shear stability, and melt viscosity [6-8]. Furthermore, this mixing and extruding system supports you in process modeling activities such as compounding polymers with additives to reduce flammability, simulating processes using only 50g of material to optimize extrusion or mixing with temperature, and profiling or extruding wires, profiles, or films in combination with rheological and optical measurements. You can fine-tune your process parameters, create test specimens, or perform quality controls on incoming and outgoing products for viscosity, dispersion, or plasticizing behavior. For that, in a torque rheometer, elements are needed to drive the measurement system (precise speed controller) and to monitor the torque (precise torque sensor). All of this information is required to process the material properly. The equipment has a heated chamber in the shape of Figure eight, with two internal rotors in the shape of semi-threads, leaving a free volume for mixing the material. This rheometer also acts as an internal mixer (roller), ideal for evaluating the evolution of torque and temperature, reactions, and influence of additives [7].

In a torque rheometer, process parameters, including rheological properties, can be inferred from changes in torque over time, reflecting changes in material viscosity during the mixing process [7,8].

The mixing of HDPE/ UHMWPE combinations is of concern to several authors due to the high melt viscosity of UHMWPE. Many studies have already been carried out in this regard, especially the main investigations regarding the mechanical properties with the processability aspects of mixing the HDPE / UHMWPE blend, the most commonly used techniques are extrusion, rheometer, etc. [9-11]. Lucas et al. [9] investigated how the mechanical behavior and wear of the HDPE /UHMWPE blend mixture (with a concentration of 10% to 30% of UHMWPE) and observed a significant improvement in both abrasion and mechanical properties, with the increase in the fraction of UHMWPE. HDPE/ UHMWPE mixtures pass by crystallization processes where both remain without any alteration in the general picture of the phase morphology [11,12].

The general objective of the project is to determine the process parameters of HDPE/ UHMWPE blends with two concentrations using the torque rheometer, varying the rotation speeds.

2 MATERIALS AND METHODS

For the development of this work used:

Commercial ultra-high molecular weight polyethylene (UHMWPE or UHMWPE) powder (UTEC batch 3041) and high-density polyethylene (HDPE) IA58 were produced by BRASKEM in the city of Camaçari - BA and the antioxidant Irganox was supplied by sigma Aldrich. The experiments were carried out by technician André Rômulo Rozado de Sousa, who was responsible for handling the torque rheometer equipment at the Polymeric Materials Laboratory (UFPB).

2.1 MATERIAL DRYING

The HDPE was dried in an oven at 70 °C for 24 hours, and the other components of the work were treated at room temperature.

2.2 TORQUE RHEOMETER

The torque rheometry tests were carried out in an internal mixer, coupled to a PolyLab OS - Thermo Scientific torque rheometer, with the operation of roller-type rotors and with a rotation speed of 10 rpm and 50 rpm, under a temperature of 190 °C, all lasting 10 minutes and with an air atmosphere. The mixing chamber mass was held constant at 50g for all samples in this work. The composition of the blends was calculated in percentage by weight, 100/0, 90/10, and 70/30, all containing 0.5g or 1% of Irganox Antioxidant.

2.3 PREPARATION OF BLENDS

The blends were prepared and mixed inside the torque rheometer mixing chamber. The temperature used was 190 °C for all mixtures and the screw speeds were 10 rpm and 50 rpm. The compositions of the blends were 0, 10, and 30% PEUAMM.

3 DATA ANALYSIS: RESULTS AND DISCUSSIONS

3.1 ANALYSIS OF TORQUE CURVES

Figures 1 to 6 show the influence of the addition of MWPEA in HDPE concerning torque as a function of time. An antioxidant was added to the mix. From the literature [14], the torque is said to be directly proportional to the viscosity, and consequently also to the molar mass of the polymeric system. As can be seen in Figure 6, the HDPE blend with 30% UHMWPE at 50 RPM rotation presented torque as a function of time lower than the blend with 10% UHMWPE at the same speed. However, due to the addition of the thermal stabilizing additive, it can be assumed that there was no decrease in viscosity and molar mass of the blend with 30% PEUAMM for rotation of 50RPM due to thermal degradation. The same is seen for the blend with 10% when compared to pure HDPE. Therefore, this behavior shows us that the higher the rotation level, the greater the initial touches of the blends. In addition, as seen in Figures 4 and 6, the torque increases over time for the blend with 30%, which may be due to the possible molecular orientation of the polymeric chains of the PEUAMM embedded in the HDPE.

Figure 1 - Torque as a function of time with the rotation of 10 RPM for o PEAD puro

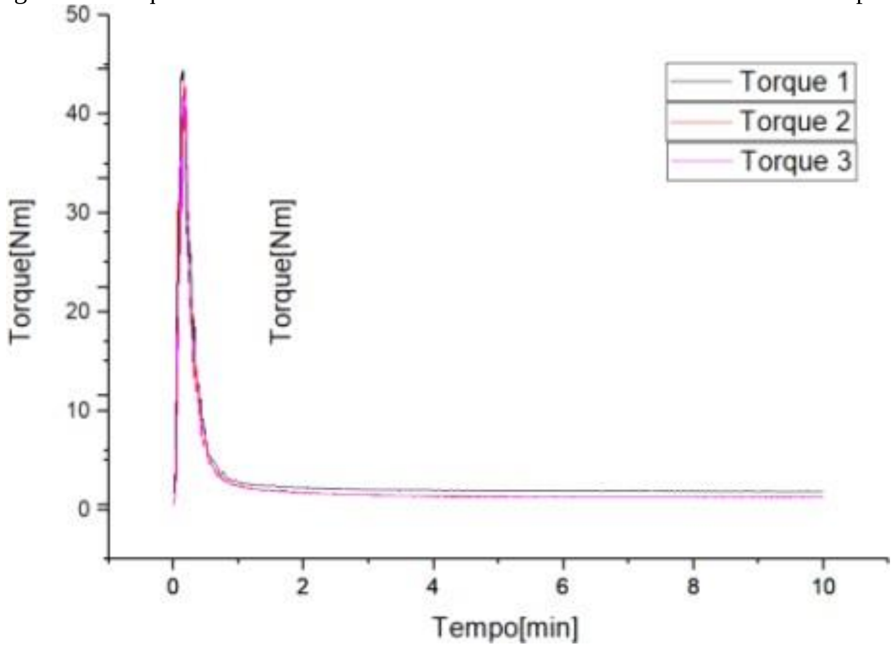


Figure 2 - Torque as a function of time with the rotation of 50 RPM for pure HDPE

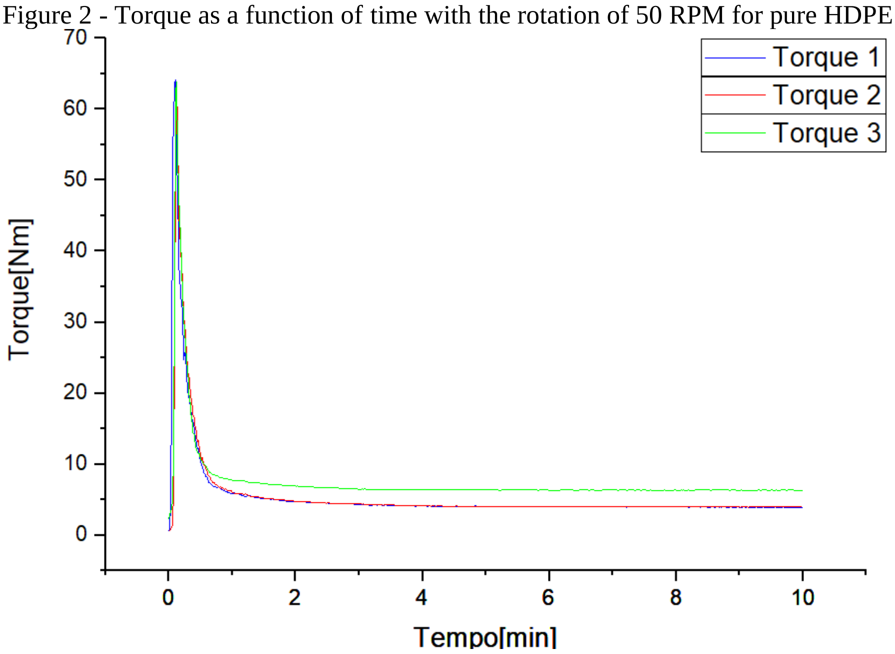


Figure 3 - Torque as a function of time with the rotation of 10 RPM for the blend with 10% PEUAMM

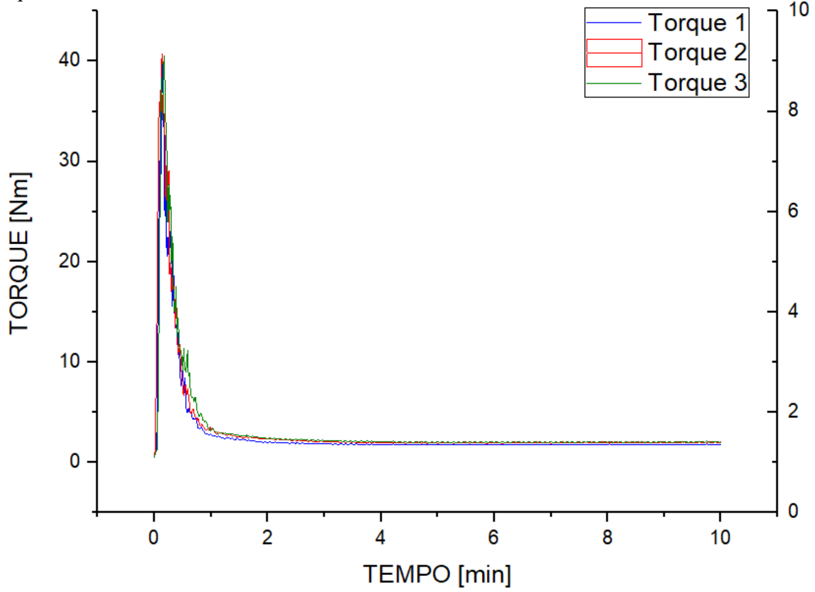


Figure 4 - Torque as a function of time with the rotation of 10 RPM for the blend with 30% PEUAMM

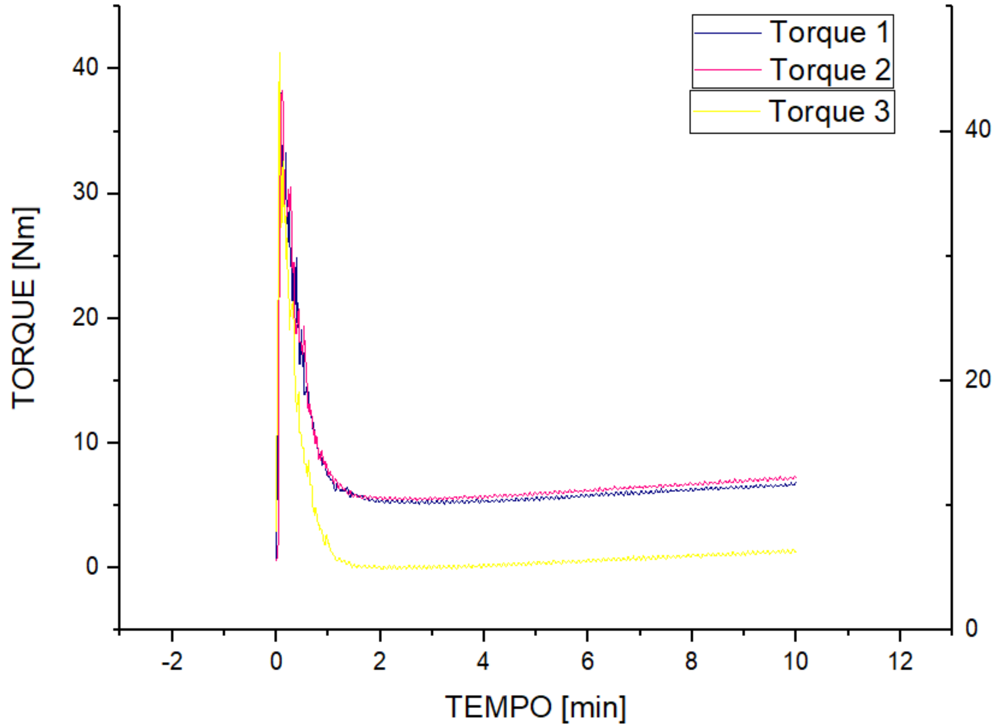


Figure 5 - Torque as a function of time with the rotation of 50 RPM for the blend with 10% PEUAMM

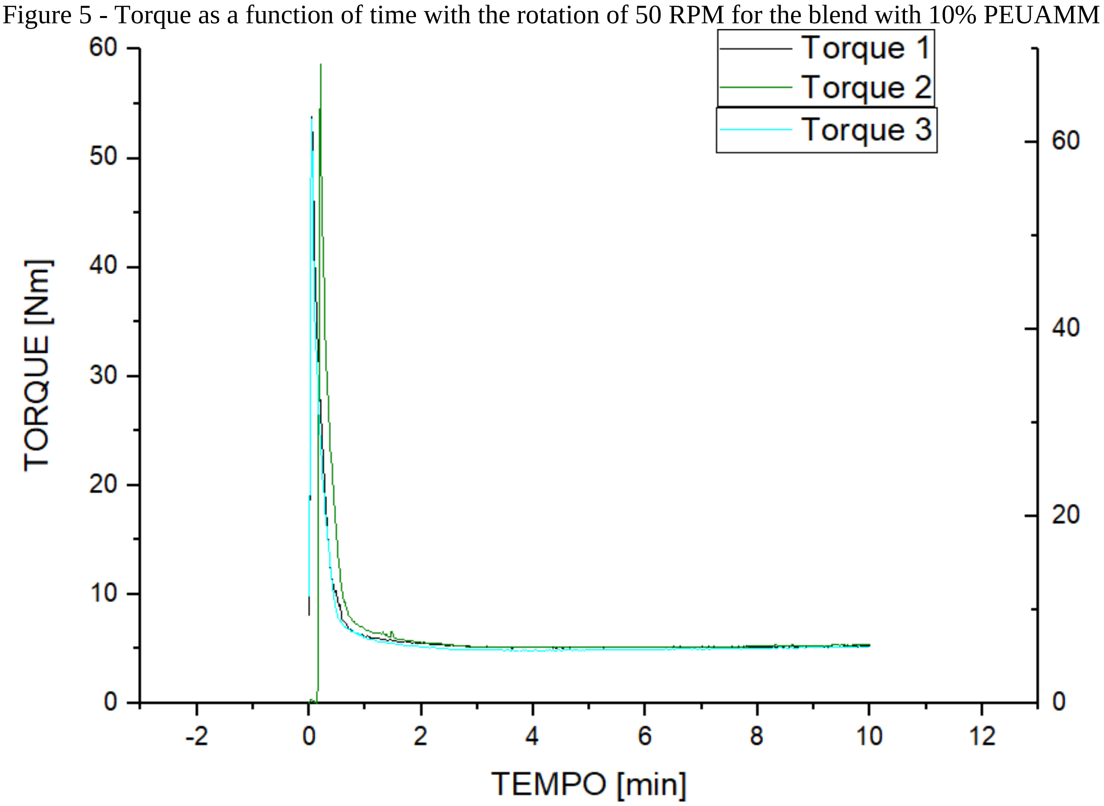
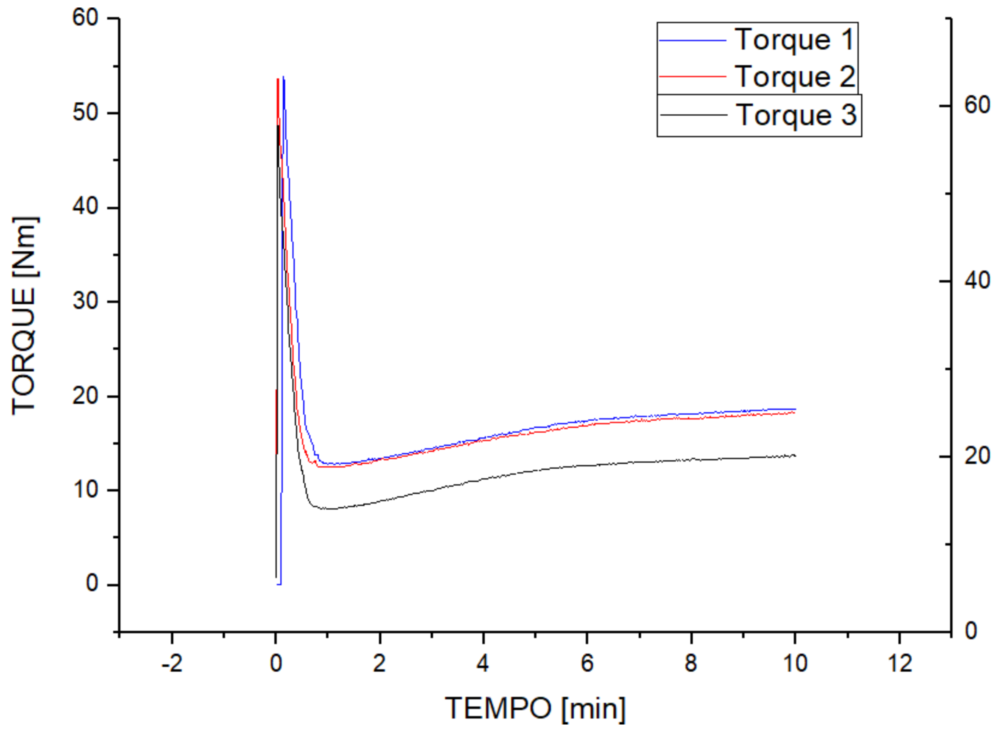


Figure 6 - Torque as a function of time with the rotation of 50 RPM for the blend with 30% PEUAMM



3.2 ANALYSIS OF MAXIMUM AND MINIMUM TORQUE VALUES

It is possible to identify and calculate the maximum and minimum torque values from the torque versus time curve. Table 1 below presents the data for the maximum and minimum torque of pure HDPE and HDPE/ UHMWPE blends.

Table 1- Maximum and minimum torque values for HDPE and blends

	Maximum torque (N.m)		Minimum Torque (Nm)	
Sample	10RPM	50RPM	10RPM	50RPM
0	42,90 ± 1,84	57,99 ± 7,03	1,57± 0,07	4,21±0,13
10	40,42 ±0, 353	61,37 ±2,31	2, 046 ± 0,18	5, 611±0,41
30	41,32 ± 4,31	55,13±2,41	5, 271±0,32	14,93±0,94

Comparing the HDPE data with those of the blends, it is possible to notice a not-very-expressive value of the influence of the maximum torque when the rotation was 10 rpm, as shown in Table 1. On the other hand, there is a slight increase in the torque of the blend with 10 % by weight compared to the blend with 30% by weight when the rotation was 50 rpm. It is notorious that the values of minimum torque for HDPE are smaller when compared with the values of the blends, mainly for the rotation of 50 RPM. HDPE has a lower minimum torque than the blends, indicating lower viscosity when reaching melt homogenization. While the higher values of the blends are an indication of more difficult processability due to the increase in melt viscosity with the addition of PEUAMM.

3.3 ENERGY VALUES

It is possible to identify from Figures 7 to 9 that the energy consumed by pure HDPE and by HDPE/ UHMWPE blends is greater when there is an increase in rotation. Furthermore, increasing PEUAMM also increased energy consumption, suggesting greater work and greater energy expenditure as a function of time. Pure polymer is the one with the lowest energy consumption value. It is important to note that the increase in composition causes the material to increase energy consumption for its processability compared to pure polymer. In the previous section it was possible to identify that the increase in composition caused an increase in viscosity during bottom homogenization (minimum torque) and, consequently, more difficulty in the flow. Based on this result, it can be assumed that the passage of the blend with 30% PEUAMM through the injection and feed channels during injection processing will be more difficult. Kyu T. et al, Divya

YOU. et al and P.Sun et al [11-13] observed that adding PEUAMM to polyolefins can improve the dense crystalline structure of polypropylene, HDPE and will further improve its tensile strength and modulus. Jaggi H. S. et al [3] reported that the viscosity increases rapidly with the increase of the UHMWPE content above 30% in HDPE, this result is in agreement with what was observed in the present study and suggested using torque rheometry.

Figure 7 - Energy variation as a function of pure HDPE processing time with the rotation of 10 RPM and 50 RP

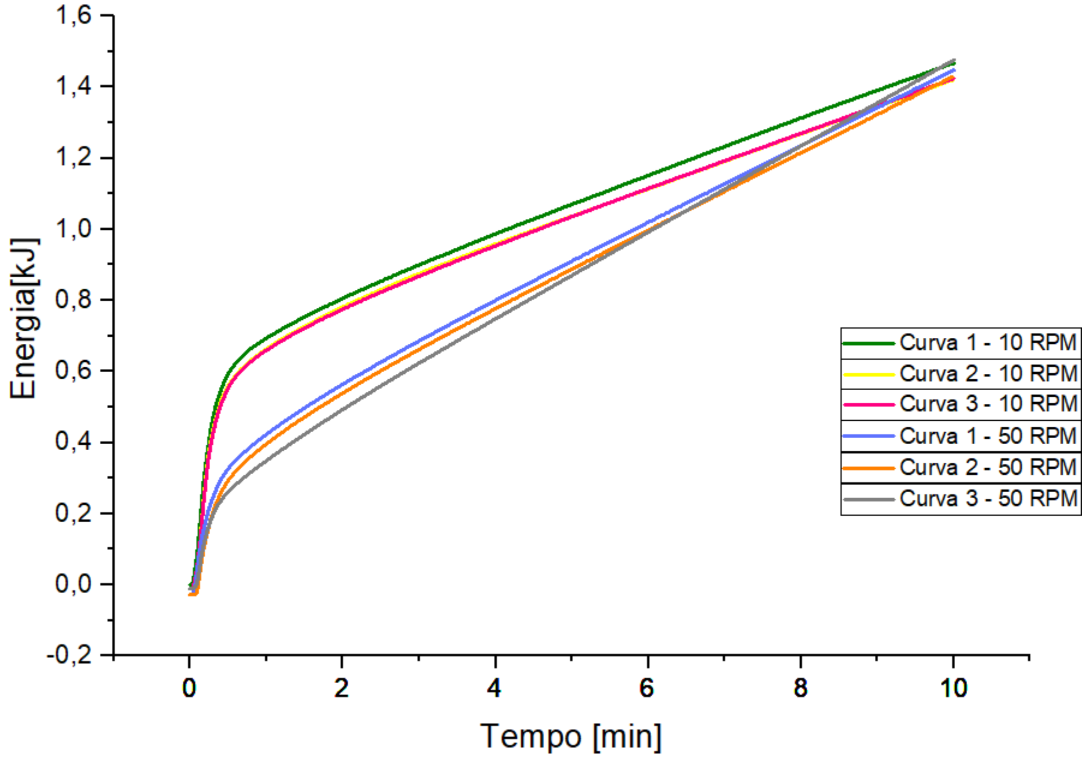


Figure 8 - Energy variation as a function of processing time of HDPE/MMWPE blends 10 RPM and 50 RPM with 10% composition.

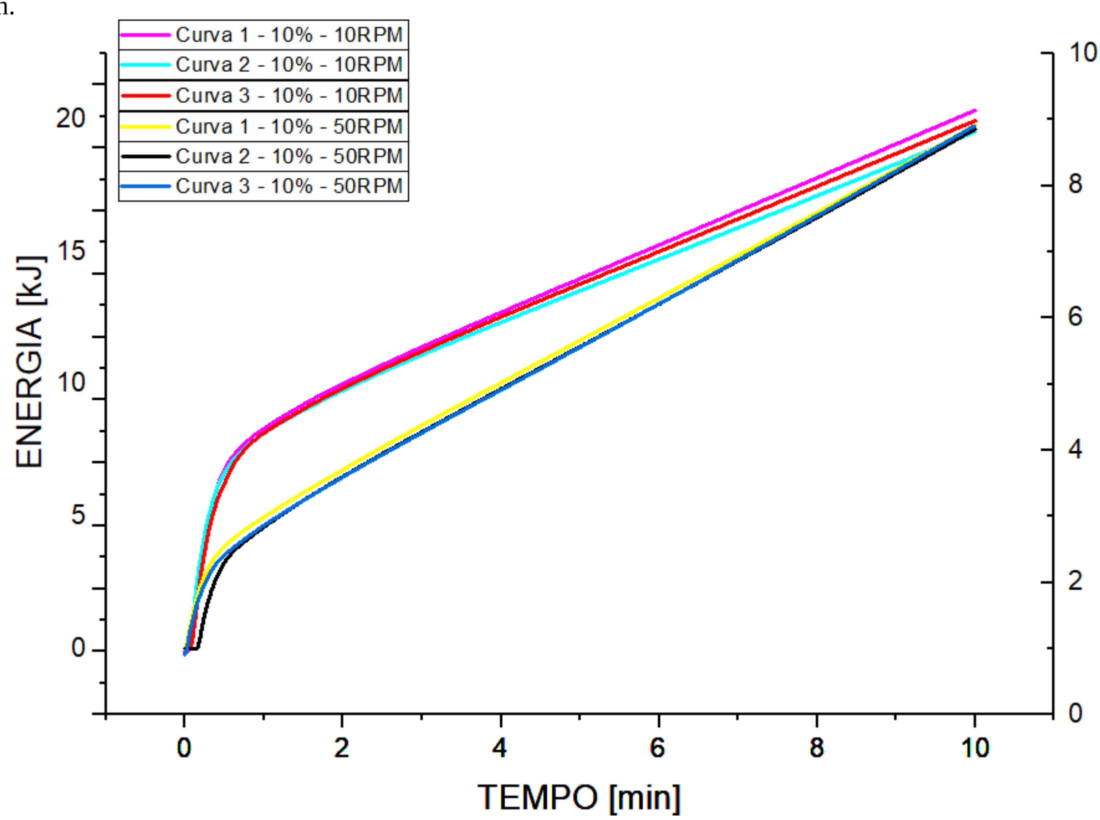
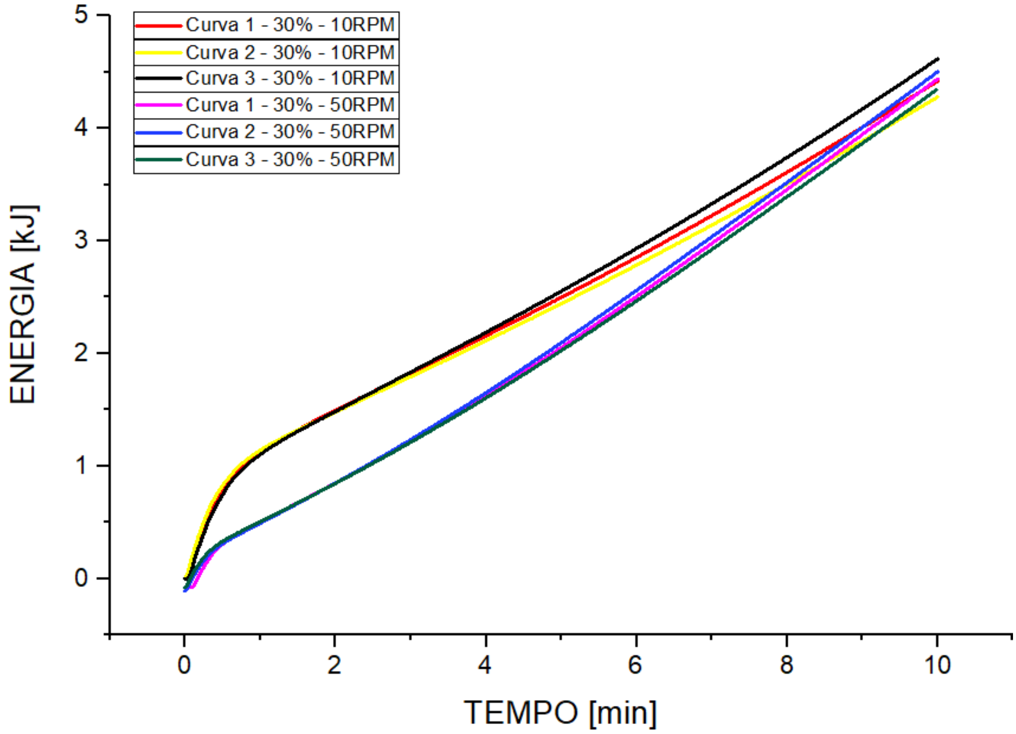


Figure 9 - Variation of energy as a function of processing time of HDPE/MMWPE blends 10 RPM and 50 RPM with 30% composition.



3.4 TEMPERATURE VALUES IN TORQUE STABILITY

Table 2 shows the temperature values at steady state for rotations of 10 and 50 rpm for HDPE and tables 3 and 4 show the values for the blends. HDPE and blend temperatures increased with rotation and blend composition. For the speed of 10 rpm, it can be seen in Table 3 that there was a slight variation in temperature between the blends, and the same trend is also observed for the rotation of 50 rpm in Table 4.

Table 2. PURE HDPE Temperature Calculation

	10 RPM	50 RPM
1st race	198,24	204,75
2nd race	198,81	200,94
3rd race	199,11	204,08
Average	198,72	203,25
D.P.	0, 441	0, 534

Table 3. 10 RPM Temperature Calculation for HDPE/MMWPE Blends

	10%	30%
1st race	198,87	199,88
2nd race	195,33	200,18
3rd race	195,47	198,85

Average	196,55	199,63
D.P.	0, 494	0, 697

Table 4. 50RPM Temperature Calculation for HDPE/MMWR Blends

	10%	30%
1st race	205,38	218,81
2nd race	206,12	220,35
3rd race	206,31	218,91
Average	205,93	219,35
D.P.	0, 491	0, 867

The greater temperature variation, with the greater rotation, is reflected in a greater mechanical work to mix the blends. It is thus possible to say that the higher rotation directly influences the temperature of the melt, which contributes to improving its processability and this will lead to a better lubricating effect, due to a smaller amount of entanglement [6].

4 CONCLUSION

Pure HDPE and UHMWPE blends, in different percentages, were evaluated for rheological properties using a torque rheometer. It was verified that the incorporation of Irganox antioxidant material gave thermal stability to the blends and thus helped, avoid degradation of the samples during the blending. The results in the dynamic regime confirmed that the rotation and the PEUAMM content affected the viscosity of the blends so an increase in the final torque revealed the possibility of molecular orientation of the PEUAMM. Energy consumption was higher with increasing rotation and concentration, as well as the melt stability temperature was increased. From these results, the processability of the pure polymer became more difficult with the addition of PEUAMM and with increasing rotation, as verified by the increase in torque during mixing.

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