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Diagnosis of polymer processing equipment by using ultrasound

Sun Zhigang[1*] *and Zhao Lijuan*[1,2]
1. *Industrial Materials Institute, National Research Council Canada, Boucherville, Quebec J4B 6Y4, Canada*
2. *Department of Materials Engineering, Polymer Research Institute, Sichuan University, Chengdu 610065, P. R. China*

Abstract: Ultrasound was used to diagnose the behaviors of a single screw extruder and an internal mixer. It was found that under the same processing conditions, the performance of the inspected processing equipment could vary noticeably. This variation in performance was found to be dependent on the past history of equipment usage. A major contributing factor to this discrepancy in processing performance was believed to be various degree of engagement of the screw or of the mixing blades in the gear box. The ultrasonic technology presented in this work can be applied to inspection of any extruders or internal mixers to help assure that the processing equipment is capable of delivering consistent products.

Keywords: ultrasound, diagnosis, extruder, internal mixer

1. INTRODUCTION

The product consistency is one of the major goals many plastic resin producers and plastic forming companies strive for. It is widely accepted that given the same resin and under the same processing conditions (in terms of pressure, temperature, production rate, etc.), the processing equipment should be able to produce identical products. However, this is only true when the processing equipment behaves exactly the same under the same settings of processing parameters. In real world, it is not uncommon to see that the quality of production varies from time to time. Most often the product producer tends to put blame on resin quality for poor product consistency. While on many occasions this is true, there are other occasions where the poor quality of the processing equipment should have been held responsible. The objectives of the present work were to demonstrate that ultrasound could be used to detect abnormity of a piece of polymer processing equipment and that such a piece of equipment could indeed behave inconsistently while keeping all the controllable processing conditions unchanged.

2. EXPERIMENTAL SETUP

One 63.5-mm FLAG single screw extruder (SSE) with a single flight barrier screw and one Brabender internal mixer (IM) with roller blades were investigated by using ultrasound. In both cases, an ultrasound probe was flush-mounted either at the end section of the barrel near the die exit of the extruder (Fig. 1(a)), or on the mixing chamber of the mixer (Fig. 1(b)). The ultrasonic probe sent ultrasonic pulse signals to the polymer and received echo signals reflected back from the rotating screw or mixing blade. Every pulse wave was reflected back and forth several times between the ultrasonic probe and screw (or blade) before completely dying out (Fig. 1(c)). In

* Correspondence to: zhigang.sun@imi.cnrc-nrc.gc.ca

the case of SSE, the inspection consisted of measuring the time it took for an ultrasound signal to travel from the ultrasonic probe to the screw flight tip and back, τ, then converting τ to probe-to-screw distance via $d = V \times \tau / 2$, where V was a known value of the ultrasound velocity in the molten polymer. In the case of IM, the amplitude of the first echo was used (Fig. 1(c)).

3. RESULTS AND DISCUSSIONS

3.1 Diagnosis of the single screw extruder

Diagnosis was carried out during extrusion of a polypropylene. Figure 2 shows an echo graphic image of the screw rotating at 20 RPM. The die pressure was P = 27 MPa. In the Figure, a total of 12,250 ultrasonic echo signals are displayed from left to right on the horizontal axis (denoted as Nb acquisition) as recorded. The vertical axis in the figure represents the sequence of sample points constituting each digitized signal. The vertical strips are the intensities or amplitudes of the 1st and 2nd ultrasonic echoes reflected from the screw flight tip when it passes in front of the UT. The count of the flight tip echoes indicates recording for 17 screw revolutions. In the Figure, two lines labeled as "Arrival lines" indicate respectively the earliest and the latest arrival positions of the 1st echo recorded during the screw rotation. In this case, radial screw oscillation of about 209 μm is evident. The screw oscillation pattern was stable and repeated itself at every second revolution. It was found that at the same screw speed and under the same processing temperature and pressure, this screw did not always perform the same. For example, in one test series, the extrusion started at 5 RPM with the die exit fully open. Then the die gap was reduced and the screw speed increased to 20, 50 and 100 RPM. After that, the screw speed was reduced back to 5 RPM. Table 1 shows the test results for this series. As can be seen in the Table, after the screw speed came back from 100 RPM to 5 RPM, the screw vibration did not return to its initial value of 0. Since extrusion quality can be much affected by the screw-barrel clearance, this highly history-dependent behavior of screw vibration suggests that this extruder would not able to produce consistent product. The data suggest that the screw deviation was rather dictated by the screw engagement into the gearbox (and possibly its condition) than the melt pressure. Once the screw was engaged in a final position (under a high back pressure), the deviation of the screw could remain pretty constant regardless of the subsequent die pressure or screw rotation speed.

3.2 Diagnosis of the internal mixer

Diagnosis was carried out during melting tests of a PET sample. It was found that this internal mixer was not able to melt the sample in a consistent manner. Figure 2 shows two ultrasonic monitoring results obtained under the same set temperature of 260 °C and at the same set blade speed of 40 RPM. The vertical axis represents the amplitude of an ultrasonic echo signal reflected from an tip area of the blade acquired when the tip was passing across the probing end of the ultrasound probe. In the first test (black), the data suggest that the PET was completely melted at about 7.5 minutes into the heating (indicated with arrow 1) and started to degrade right after. In the 2nd test (gray), the evolution of ultrasonic echo amplitude looks quite different from the 1st test and suggests that the heating process was taking place at a slower pace and that the melt started to degrade at about 10.5 minutes into the heating (indicated with arrow 2), which was about 3 minutes later compared to the first test.

4. CONCLUDING REMARKS

Neither of the polymer processing equipment investigated in this work was diagnosed satisfactory for lack of the capability to produce consistent results. As a matter of fact, both of them were over 20 years old. The ultrasonic technology presented in this paper can be a good diagnostic tool for manufacturers of polymer processing machines or end users of these machines to gain some insight on the characteristics of their machines which cannot be obtained easily otherwise.

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TABLE 1. Results of the one test series listed in a sequential order of the tests

Test #	Screw speed (RPM)	Melt pressure (MPa)	Screw deviation (μm)
1	5	2.4	0*
2	20	5.3	64
3	20	16.2	113
4	50	20.3	146
5	100	25.9	147
6	5	8.1	130

*: 0 represents the case where screw deviation was not noticeable.

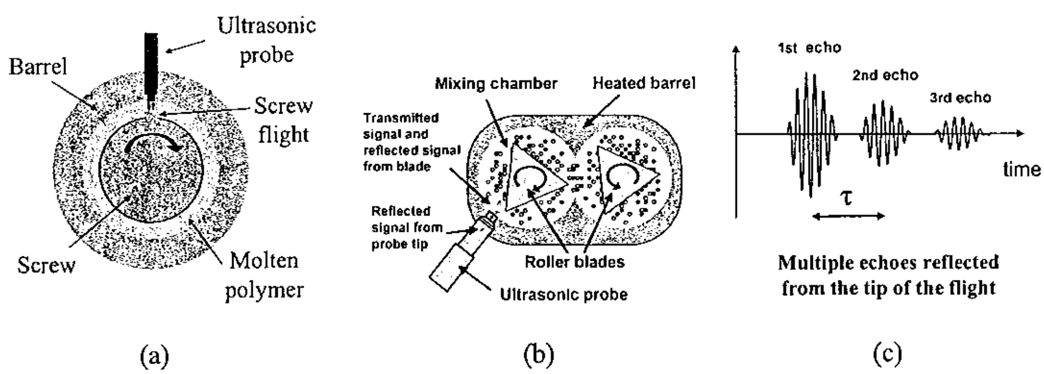

FIGURE 1. Installation of an ultrasonic probe (a) at the end barrel section of a single screw extruder, and (b) on the mixing chamber of an internal mixer. The travel time between the probe end and the flight of the screw (or blade) was obtained by measuring the time delay between the first and second echoes (c).

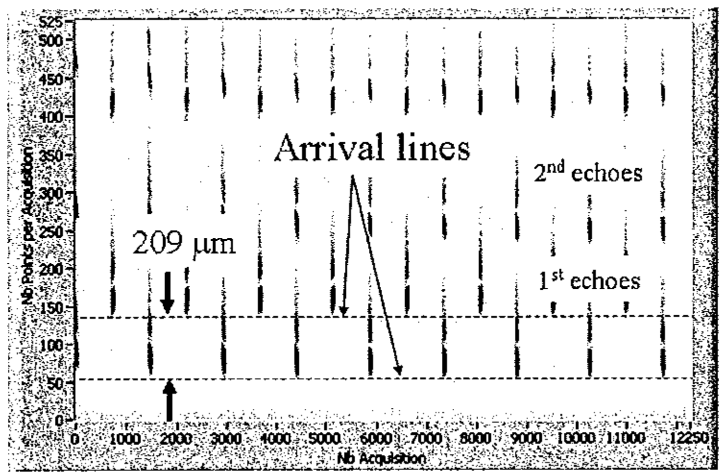

FIGURE 2. Echo signals reflected by the screw during a test at 20 RPM.

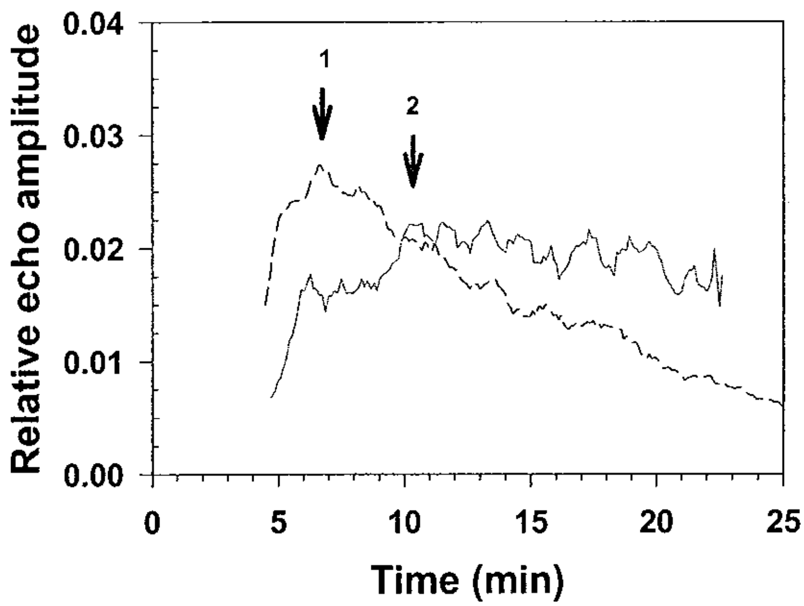

FIGURE 3. Ultrasonic echo amplitude measured during two melting tests of a PET sample on the internal mixer, both at 260 °C and 40 RPM.