Ultrasonic Response of Polymers by Non-contact Transducers

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Ultrasonic waveform is one of the parameters that characterize a material.Thus, in this paper, the authors aim to visualize and characterize different waveforms of a POLYPROPENE FOIL F-401. The experiment is made with non contact transducers (the resonance frequency is 50 MHz) by applying the method through transmission. There are determined the acoustical and spectral parameters such as the propagation velocity, the time of the flight of the ultrasound, the pulse width, the bandwidth, the peak frequency and its amplitude. The waveform without the sample beeing placed between the transducers (transmitter-receiver) is considered to be the reference. Then, the sample is placed between the transducers at different distances from the transmitter. These waveforms are compared and analysed relative to the reference.

Keywords:ultrasounds, non-contact transducers, polymers, ultrasounds waveforms

Ultrasonic response analysis is tipically limited to amplitude and time of the flight measurement. For many applications, these parameters are sufficient for satisfying control requirements and for taking the right decision for retrieving eventual defects. However, this level of analysis could be insufficient for some types of defects or materials that require more elaborate procedures and algorithms in order to solve the specific problem [1].

Ultrasonic response waveform contains considerable more information regarding acoustical parameters (amplitude, velocity, attenuation, time of the flight) from the time domain and spectral parameters (peak frequency, bandwidth, pulse width) from the frequency domain, having the possibility to identify the examined sample.

In order to rercicle polymer materials, it is necessary to identify and analyze them; economical conditions require to use simple methods and reduced response times.

Knowing that macroscopic physical methods based on density measurements are not sufficient for polimers identification, ultrasounds were used to investigate molecular or structural properties of polimers. Propagation velocity, ultrasonic attenuation and spectral characteristics of ultrasonic response are the most relevant measurement acoustical parameters [2]. Thus, propagation velocity depends directly on elasticity parameters and density. Ultrasonic energy is absorbed or attenuated bellow different levels in different types of polimers, being governed in a complex mode by the interactive effects of density, hardness, viscosity and molecular microstructure.

Analyzing different types of polimers with ultrasonic transducers, one can conclude that their response from the spectral point of view behaves as a low-passing filter attenuating high frequency levels of a wideband ultrasonic wave more than the low frequency levels.

Considering that the frequency of a wideband pulse that propagates through a material, determines an accentuated attenuation of the signal, in this paper, one emphasize and analyze ultrasonic response attenuation for each investigated situation, in order to characterize the waveform. In the frequency domain, analysis can be made assuming that all systems are linear and invariable in time. Development of noncontact or air transducers presents the advantage of more applications such as porous, pharmaceutic, granular, hygroscopic materials, etc [3]. These transducers eliminate the disadvantage of examination with liquid (water, immersion) or paste couplant.

The classical model of fluid compressibility [4,5] assumes the existence of the definition relation:

$$p = p(\rho) \qquad (1)$$

between density ρ and pressure *p*. In Laplace adiabatic assumption for an ideal gas (air), one have the relation:

$$p = k\rho^{\gamma}$$
$$\gamma = \frac{c_p}{c_v} \qquad (2)$$

where *k* – is a constant and represents the pressure reported at the environment density which, after Laplace remains constant in time and γ is the ratio between the specific heats c_p and c_v (γ=1,4 for air). For velocity *v* determination, relation (2) is derived and it can be obtained:

$$v^2 = \frac{d}{d\rho}\left(k\rho^{\gamma} \right) = \gamma k\rho^{\gamma-1} = \gamma\frac{p}{\rho} \qquad (3)$$

Since p = ρ*RT* (ideal gas equation resulting from Boyle law and from absolute temperature T definition):

$$v = (\gamma RT)^{\frac{1}{2}} \qquad (4)$$

For dry air R = 287 J/(Kg.K), thus at temperature of 0^0C (273,16K) according to relation (4) it can be obtained the value for sound velocity in dry air:

$$v = (\gamma RT)^{\frac{1}{2}} = (1.4 \cdot 287 \cdot 273.16)^{\frac{1}{2}} = 331 \, {}^{m}\!/_{s} \qquad (5)$$

For other temperatures, it is sufficient to develop, in Taylor series, the velocity around the temperature of 273,16K as follows:

$$\frac{dv}{dT} = \frac{1}{2} \cdot \frac{v}{T} \text{ or } \ \mathbf{0.61\ m/s\ la\ t= 0^0C.}$$

Thus, in the end, is obtained the expression for ultrasonic velocity in dry air(2) in m/s and the temperature in degrees Celsius (*t*):

$$v = 331 \pm 0.61 \cdot t \qquad (6)$$

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Experimenal part

The experimental set-up that represents through transmission technique with ultrasounds is shown in figure 1. After generating the pulses, these are transmitted to an emitter (E) and received at the exit of the examined sample (R).

Since the signal is attenuated at the exit from the receiver, it must be amplified, and for the time domain it was applied Fast Fourier Transform (FFT).

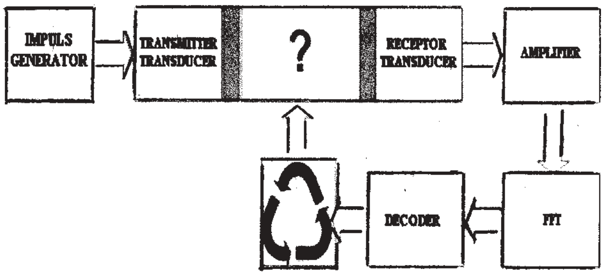

Fig. 1 The experimental set-up that represents through transmission technique with transducers E-R

There are used two non-contact transducers: an emitter (E) and a receiver (R) at 400 mm distance in air between them [6]. Operating frequency is 50KHz with an iteration of 225Hz. Voltage value at the emitter is 10 V and at the receiver is 3 V. Transducer active diameter is 12.35 mm. Air is used as a couplant. The examined sample consists of a polypropene foil F-401. Time of the flow (ICT) is 180 s and the thickness is 0.56 mm.

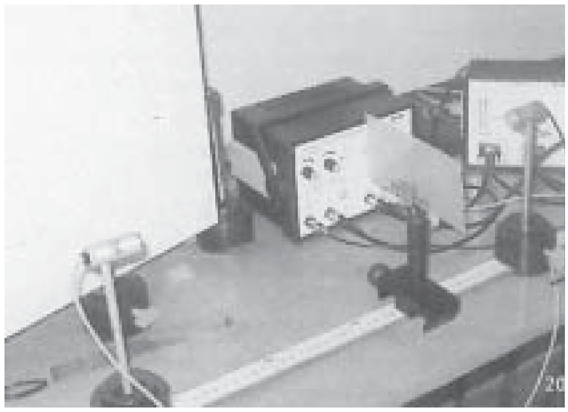

Fig. 2 Experimental set-up

The experimental set-up is shown in figure 2 where the polimer sample F-401 is placed on the ultrasonic beam axis between E-R, at different distances from the emitter (E). In all studied cases, after determing the waveform with or without the sample being placed between E-R, there are determined acoustical parameters such as peak frequency (fp), bandwidth (Δf), amplitudes afferent to growth (tc) and falling (td) times, RF pulses and also the ratio between times t_1 and t_2 afferent to the first two RF signal cycles (TPR) [7] as the ratio between peak frequencies from the time domain and their afferent amplitudes. The aspect of the waveform obtained without the sample beeing placed between E-R at 400 mm distance (sample 400), shown in figure 3a, is considered to be the reference.

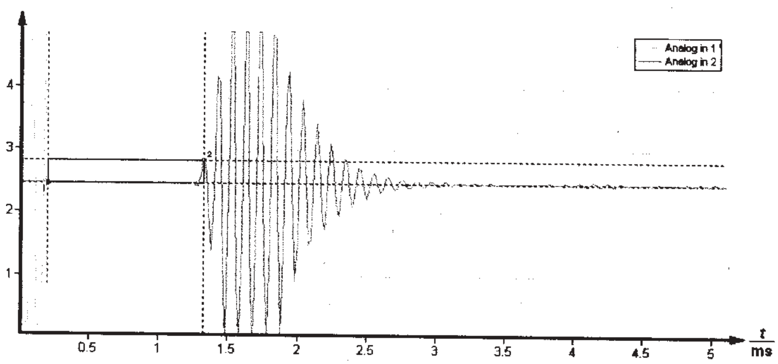

Fig. 3a. Ultrasonic waveform for 400

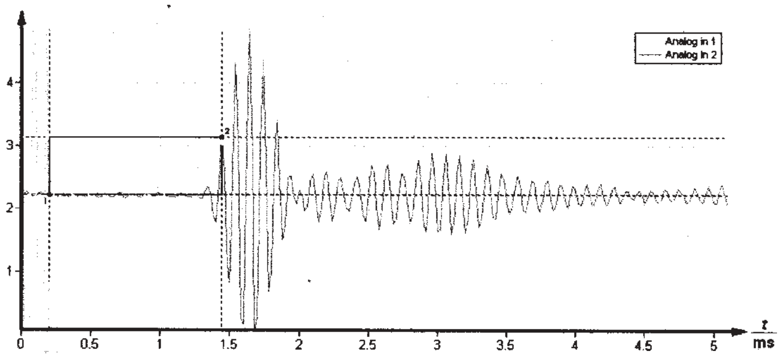

Fig. 4a. Ultrasonic waveform for 100f

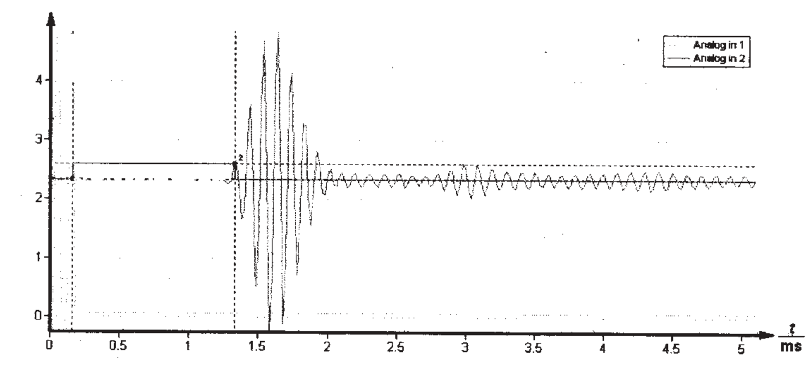

Fig. 5a. Ultrasonic waveform for 200f

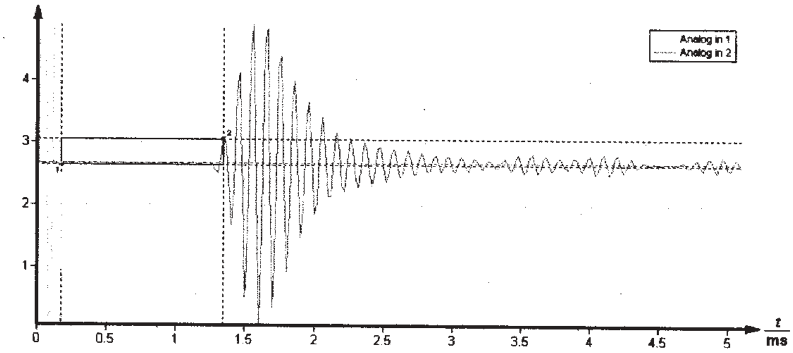

Fig. 6a. Ultrasonic waveform for 300f

Then, the polymer sample F-401 is placed on the ultrasonic beam axis between E-R, at different distances from the emitter (100f mm, 200f mm, 300f mm) and the aspect of the waveform is recorded (figs. 4a, 5a,6a).

Results and discussions

Examining the refence (without the sample and noted with 400) one notice that the aspect of the waveform in the time domain, presents an amplitude maxima (4.91V) at the propagation time of 1.530 ms E-R, with a large well defined exponential decrease. When the sample is placed at 100f mm distance from the emitter, a change of the waveform with secondary impulses is noticed , and a single amplitude maximum appears at 4.86V at 1.641ms with a sudden exponential decrease; at the distance of 200f mm the aspect of the waveform is changed (there are no secondary impulses), the amplitude maximum is at 4.87V but has the same ultrasonic propagation time of 1.641 ms; at 300f mm the aspect of the waveform is changed, the exponential decrese is more smooth and well defined, with easy visible secondary impulses having the maximum at 4.92V with 1.563 ms The change of the aspect of the waveform for different situations it is also noticed in table 1 at the times tc and td depinding on the distance between the emitter and the sample. A RF impulses growth time (tc) decrease has a reverse reaction of time growth (td) on the decresing side of the impulses relative to the distance from the emitter. Instead, the amplitudes afferent to these times (Uc and Ud) show identical values. The thickness in time of the impulses train is another parameter that is caracteristic for the waveform and, according to table 1, shows a contraction towards small distances (100f mm and 200f mm). Regarding the acoustic parameter TPR from Table 1, a monotone variation with the distance from the emitter and a change of the positive-negative sign of the RF signal with the sample departure from the emitter are noticed.

Table 1
ACOUSTICAL PARAMETERS

Sample	tc(ms)	Td [ms]	Uc [V]	Ud [V]	Thickness in time Δt	TPR
400	0,196	0,915	2,08	2,21	1,111	0,838
100f	0,302	0,292	2,30	2,35	0,594	0,938
200f	0,299	0,286	2,26	2,05	0,585	0,942
300f	0,206	0,796	1,86	1,94	1,005	0,941

The experimental determination of the propagation velocity [8] of ultrasound through air was realized by measuring the times between ultrasonic response emission and reception for the four situations. In the aproximation of a rectilinear and uniform motion of ultrasonic waves is applyed the relation of velocity and its value for the distances 400 mm,100f mm, 200f mm, 300fmm is found (6) at t =25°C.

Table 2 contains the experimental values and the theoretical value v = 346.25 m/s

Table 2
TIME OF THE FLIGHT AND ULTRASONIC WAVES VELOCITY THROUGH AIR AT DIFFERENT DISTANCES

Sample	Time[ms]	Velocity[m/s]	Relative deviation
400	1,123	356,18	0,028
100f	1,240	322,58	0,068
200f	1,172	341,30	0,014
300f	1,171	341,58	0,013

Table 2 analysis shows that the experimental values of ultrasound propagation velocity in air in the case of the existence of the sample between emission and reception are closer to the theoretical value in the case without the existence of the sample (400 mm).

Using FFT in the time and frequency domains [9,10] can be obtained the peak frequency, the value of amplitude afferent to the peak frequency and the bandwidth.

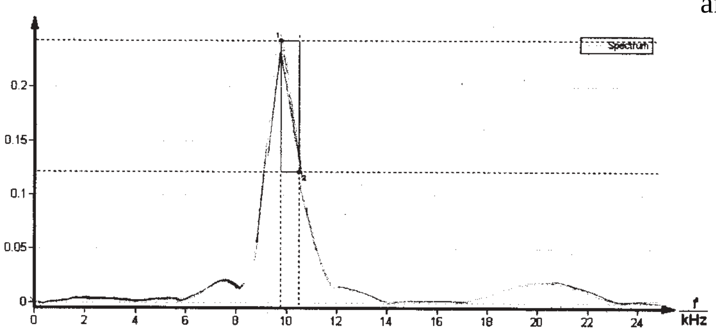

Fig. 3b Peak frequency for 400

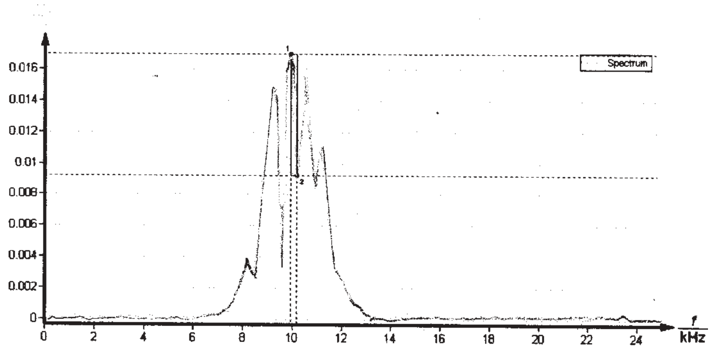

Figure 4b Peak frequency for 100f

Fig. 4b Peak frequency for 100f

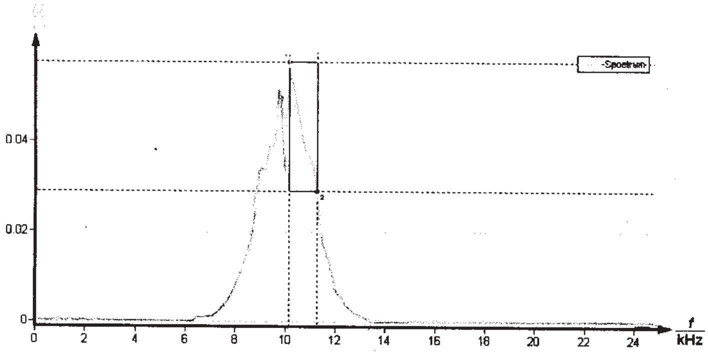

Fig. 5b Peak frequency for 200f

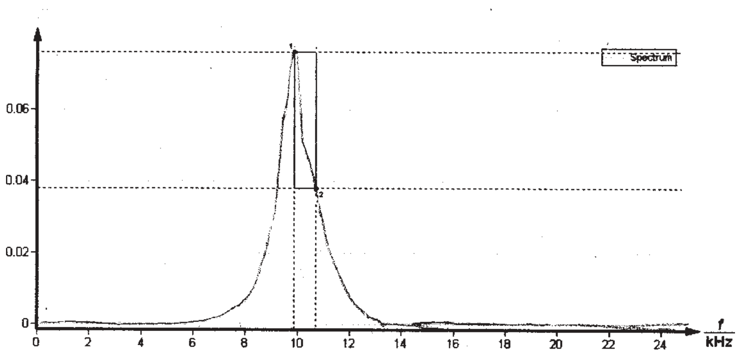

Fig. 6b Peak frequency for 300f

Fourier analysis of ultrasonic response shows an increase of peak frequencies especially at the distance 200f mm and the bandwidth is decreasing with the increase of the distance (table 3) and the same thing happens to the value of amplitude afferent to the peak frequency.

Table 3
SPECTRAL PARAMETERS

Sample	Peak frequency Fp[KHz]	Bandwidth Δf [KHz]	Amplitude [V]
400	9,790	0,953	0,242
100f	9,954	1,675	0,017
200f	10,152	1,053	0,058
300f	9,873	0,766	0,076

Conclusions

In this paper, the authors visualized and analyzed different waveforms of a POLYPROPENE FOIL F-401 of 0.56 mm thickness. The experiment is made with two non contact transducers (the resonance frequency of 50 MHz) by applying the method through transmission.

Analysis of the ultrasonic waveform through the polimer sample shows:

in the time domain:

-a well defined exponential decrease of impulses with the increase of the distance of the sample from the emitter;

-the thickness increases in time approaching the value obtained without the sample;

-the parameter TPR shows equal values for the three positions of the sample which shows constancy in the first two cicles of the RF signal.

in the frequency domain:

-peak frequencies are different but closer;

-the bandwidth decreases with the increase of the distance from the emitter and the amplitude increases;

-a significant change of impulses waveform appears with the departure from the emitter meaning that the signals are strongly attenuated, amplitude peaks are smaller and more reduced and also more secundary impulses appear.

Complete visualization of the ultrasonic waveform shows different aspects in the three positions. One notice that these aspects are completely different from the aspect of the waveform without the sample. Thus, one consider that knowing the ultrasonic waveform and acoustical and spectral parameters, in a good approximation, it can be identified and characterized the examined sample.

Concerning the determination of the ultrasounds propagation velocity in air, from Table 2, one notice that the velocity variation with the distance from the emitter is within the admissible limits. Errors appear due to the fact that ultrasounds propagate through air and the distance between E-R is bigger and there could appear influences of the air pressure and temperature (of the environment).

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