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Material behaviour

Temperature dependency comparison of ultrasonic wave propagation between injected and sintered thermoplastics

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ABSTRACT

Active touch localization based on a learning process of touch-disturbed broadband bending wave propagation in thin objects is used to transform any 3D surface into a multi-touch interface. Fast prototyping permits easy manufacturing of various 3D shapes that can be as quickly transformed into touch interfaces. The drawback is their weak mechanical stability with temperature. This paper details the temperature behavior differences between a sintered plastic such as polyamide polymer of type PA12 and raw injected Acrylonitrile-Butadiene-Styrene composite polymer (ABS), in particular how their physical parameters such as Young's modulus and Poisson's ratio are affected by temperature. Correlatively, longitudinal and transversal waves within injected and sintered plastics are investigated across a commercial temperature range of 10 °C to 70 °C. The internal grain structure in plastics obtained by laser sintering of powder makes these materials prone to stronger damping and clear non-linear temperature dependency of the shear wave velocity compared with injected plastics.

1. Introduction

Human computer interfaces (HCI) can be found in familiar objects of our daily environment. In recent years, touch sensitive shells of any shape have been proposed based on an ultrasonic learning process in which the localization of a touch is derived from the diffraction pattern disturbance of a bending wave generated at various frequencies [1]. A localized touch on a finite object creates a unique disturbance of the acoustic wave that can be recognized to estimate the position of the contact. Usual approaches for estimating the touch position use either shell modes in a permanent regime [2], or transient regime [3]. In any case, the disturbance, which is a combination of viscous absorption and diffraction effects, is very small, of the order of a few percent. For large and thick objects, the touch disturbance may be so small that direct transmission between the emitting and receiving transducers must be avoided [4]. In addition, it drastically depends on the way acoustic waves propagate in the shell. It is known that temperature greatly impacts the mechanical properties of materials, and thus the propagation of acoustic waves. As a consequence, temperature variation has a strong effect on the algorithm recognition efficiency. For instance in [5], two signals taken at different temperatures cannot be reliably correlated because of thermal expansion. Additionally, the effect of temperature variations on a diffuse ultrasonic field is not necessarily linear with temperature, so that the modeling of temperature effect as a linear stretching of the frequency spectrum [6] is incorrect, especially in thermoplastics. Therefore, it is necessary to

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measure the impact of temperature on viscoelastic properties of these materials.

In this paper, we investigate temperature and humidity dependency of fundamental waves in Acrylonitrile-Butadiene-Styrene polymer (ABS) and sintered polyamide of type “PA12”. Such dependency has not been studied previously. ABS is commonly used in industry, whereas PA12 has emerging use in 3D fast prototyping techniques such as Selective Laser Sintering (SLS).

The paper deals first with a description of the experimental set-up in Section 2. Then, in the following two sections, the mathematical treatment to determine transit times of elastic waves through the sample materials is discussed in terms of diffraction and expansion. In Section 5 and Section 6, results on velocity and damping measurements are presented in a temperature range of 10 to 75 °C and for 40 to 80% RH. These results are then discussed and analyzed in the last section before conclusions in order to estimate viscoelastic properties of ABS and PA12.

2. Set-up and protocol

A through transmission technique was used to study the temperature effect on propagation of fundamental waves in two sample materials: injected ABS and sintered PA12. The ABS was bought in plates of different thicknesses. We used a material with commercial name Tecaran manufactured by Ensinger [7] (Nufringen, Germany). Sintered plastics were obtained by SLS in which small powder particles are fused with a laser, layer by layer, to form 3 dimensional objects. In our case, a polyamide PA12 polymer powder was used. The manufacturer 3DSystems [8] (Rock Hill, USA) specifies a mean grain size of 58 μm, with a size dispersion ranging from 25 to 92 μm representing 90% of the particles. Plates of these materials were used and thicknesses were measured using a caliper with accuracy of ±0.01 mm.

The set-up comprises a pair of piezoelectric transducers attached on each side of a plate with a coupling agent (Panametrics SWC – Shear Waves Couplant), as illustrated in Fig. 1(a). A wave is sent through the material from an emitter to a receiver. The sample is placed in a climate chamber KMF240 (Binder, Germany) in order to evaluate thermal coefficients of velocity. Precision is enhanced by using two different thicknesses for each material. Velocities are deduced from transit-time difference over the temperature range. Fundamental waves are excited with a 20 Vpp tone burst of one period sine wave provided by a signal generator, Tektronix AWG3022. Reception is done with a PICOSCOPE ADC212 acquisition board featuring 12 bits of vertical resolution at 50 MSa s^{-1}. All measurements consist of 64 averaged acquisitions and are transferred to a computer and handled in the Matlab environment. Longitudinal and transversal waves are selectively detected using two different Non-Destructive Testing (NDT) transducers from Panametrics (Waltham, Massachusetts). Shear waves are detected at a 1 MHz central frequency with a V153 type, whereas longitudinal waves are detected at a 5 MHz central frequency with the Panametrics M110 type. Transducers face each other and are held tight against the sample by spring loaded clips under a force of ∼10 N in order to limit the thickness of the viscous couplant (Panametrics SWC) used both for longitudinal and shear waves. This couplant is sufficiently viscous to transmit transversal waves at temperatures up to 38 °C according to the manufacturer’s datasheet. In practice, arrival time can be distinguished at temperatures well above this limit, particularly for longitudinal waves. An example of received signals for two different thicknesses of ABS is illustrated in Fig. 1(b).

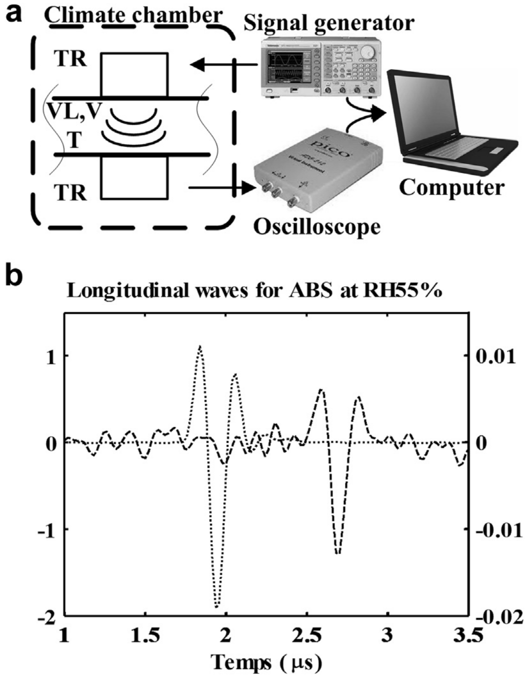

Fig. 1. (a) Set-up with samples conditioned in a climate chamber. Signal generation and data acquisition are controlled in the Matlab environment. (b) Examples of acquired longitudinal waves in ABS (vertical scale in mV). Dotted line: 3 mm thick material. Dashed line: 4.5 mm thick material.

Samples are then placed in the climate chamber for controlling the temperature between 10 °C and 75 °C at three different constant Relative Humidity (RH) values of 40%, 55% and 80%. Standard operating condition for a touch interface is RH = 55% whereas RH = 40% and RH = 80% are extreme conditions. Temperatures are logged with a thermocouple coupled to the sample material with thermal paste.

All measurements were repeated on the occasion of various measurement campaigns under the same conditions.

3. Diffraction effect correction

Since the velocity is determined by fine measurement of the transit time, the diffraction phenomenon has to be accounted for. For that purpose, let us express the velocity from the potential of velocity field $\vec{v} = -\vec{\nabla}\phi$ and for a monochromatic wave $\phi(R,t) = \phi(R)\mathrm{e}^{i\omega t}$, the Rayleigh integral in cylindrical domain defines the potential ϕ: