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Measurement of velocity and attenuation for ultrasonic longitudinal waves in the polyethylene samples

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Abstract

The plastics pipes are used widely for water and gas supplies and for different applications in industry. The non-destructive testing (NDT) of the welded joints of such pipelines is very important for the safety and long live time of them. The main technique used for it is ultrasonic NDT. The specific physical-mechanical properties of the plastics used for manufacturing of the pipes require the ultrasonic properties of them to be well known. The aim of investigations described in this article is to measure the velocity and the attenuation of ultrasonic longitudinal waves in the material of plastic pipes. The set of polyethylene PE80 test samples of different thickness in the range from 2.5 mm up to 20.0 mm were investigated. The measurements were performed using contact through-transmission technique and ultrasonic transducers with the central frequencies 1.0 MHz, 3.0 MHz and 5.0 MHz. The measurement results demonstrate dependences of the measured ultrasonic properties on frequency. It was determined that the velocity of ultrasonic longitudinal waves varies from 2030 m/s to 2060 m/s when the frequency is changing from 1.0 MHz to 3.5 MHz. The attenuation of ultrasonic longitudinal waves in the same range of frequencies varies from 0.3 dB/mm up to 1.5 dB/mm.

Keywords: ultrasound velocity measurements, longitudinal waves, attenuation, polyethylene, plastics.

Introduction

The plastic pipes made of polyethylene (PE80) are very widely used in the pipelines of water and gas supplies. The diameters of pipes vary from 90 mm to 1000 mm and wall thickness – from 10 mm to 50 mm. Two main techniques for welding of plastic pipes are used in practice: butt fusion welding and electro-fusion welding. In both of these techniques the heating of the welded zones of plastic is used. It can have influence into mechanical and acoustical properties of the plastics used. The non-destructive testing (NDT) of the welded joints of such pipelines is very important for the safety and long live time of them. The main technique used for it is ultrasonic NDT.

The plastics itself are relatively new structural materials and due to relatively high attenuation provide significant challenge for NDT [1-3]. There are various techniques used for estimation of acoustic properties of material [4-7]. However any changes in manufacturing technology lead to the changes of acoustic properties. In the case of the manufactured pipeline the parameters of plastics not determined accurately.

The wide range of pipe dimensions defines the size of areas to be tested. So, the zones to be tested can vary significantly. The ultrasonic parameters of tested plastics such as velocity and attenuation of longitudinal waves and its dependences on frequency should be well known. These parameters are necessary for calibration of NDT equipment, measurement of wall thickness and for numerical modelling which is used during inspection technique development. So, the objective of presented investigations was to measure the velocity and the attenuation of ultrasonic longitudinal waves in the material of plastic pipes.

Set-up of experiment

The experimental investigations were performed on the set of 8 test samples. The spatial dimensions of the test samples are 50.0 mm×50.0 mm. The thicknesses of them are different: 2.5 mm, 5.05 mm, 7.57 mm, 10.0 mm, 12.57 mm, 15.0 mm, 17.57 mm and 20.19 mm. They are manufactured from the PE80 type polyethylene pipe section in parallel to the pipe side surface.

All test samples were investigated by contact through-transmission technique. The investigations were performed using ultrasonic measurement system “ULTRALAB” developed by Ultrasound Institute of Kaunas University of Technology. The wide band ($\Delta f \geq 0.5 f_0$) ultrasonic transducers with the centre frequency 1.0 MHz, 3.0 MHz and 5.0 MHz were used for the measurements. The set up of the performed investigations is presented in Fig. 1. It enables to perform the measurements in the pitch-catch and the pulse-echo modes.

The ultrasound velocities were estimated by measurement of delay time between signals obtained on the test samples with different thickness and the signals obtained for the thickness of 2.5 mm. The delay time was estimated using cross-correlation technique. As the reference signal the front part of the signal measured for the 2.5 mm thickness was used (Fig. 2).

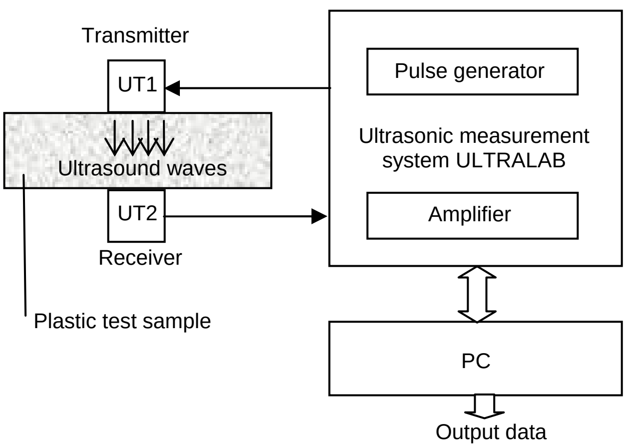

Fig. 1. **The set up of ultrasonic measurement system for investigation of the properties of the longitudinal ultrasonic wave's propagation in the PE80 type polyethylene test samples**

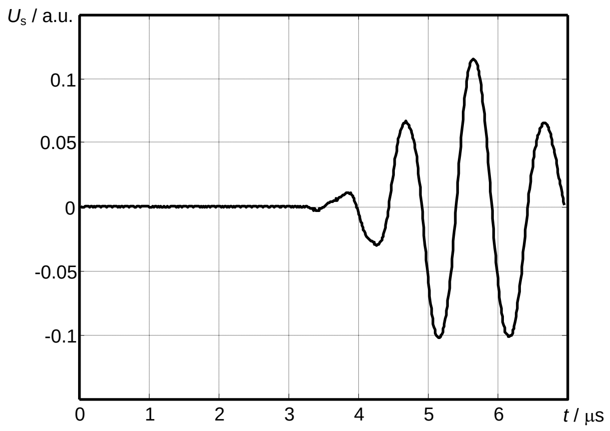

Fig. 2. **The 1.0 MHz frequency signal passed through 2.5 mm thickness of PE80 type polyethylene test sample used as the reference signal for estimation of ultrasound velocity by cross-correlation technique**

The results

The obtained values of ultrasound velocity for different propagation distances at different frequencies are presented in Table 1. In Fig. 3 – Fig. 5 are presented dependencies of determined velocities versus the propagation distance for the frequencies 1.0 MHz, 3.0 MHz and 5.0 MHz correspondingly.

If to exclude the values obtained at two smaller distances the mean value of the ultrasound velocity at 1.0 MHz is 2230 m/s. The mean value of ultrasound velocity at 3.0 MHz is 2249m/s and at 5.0 MHz - 2255m/s.

Table 1. **The values of measured ultrasound velocity of longitudinal waves for the different distances and at different frequencies**

Propagation distance, mm	*c*, m/s, at 1MHz	*c*, m/s, at 3MHz	*c*, m/s, at 5MHz
2.55	2265	2265	2271
5.07	2203	2247	2247
7.5	2239	2257	2262
10.07	2234	2250	2256
12.5	2231	2251	2255
15.07	2225	2247	2254
17.69	2221	2241	2248

The value of ultrasound velocity, obtained for the passed distance of 5.07 mm, which not correspond to the consistent of the results for other passed distances, probably can be explained by different origin of the test sample, or by different thermal conditions of its manufacturing.

The investigations show existing dependence of velocity of longitudinal ultrasonic waves propagating in PE80 type polyethylene on the frequency (Fig. 6)

The received ultrasonic signals have the spectrums shifted to lower frequency side. So, the dependence of velocity of ultrasonic waves is presented for the shifted, but not central frequencies of the transducers used.

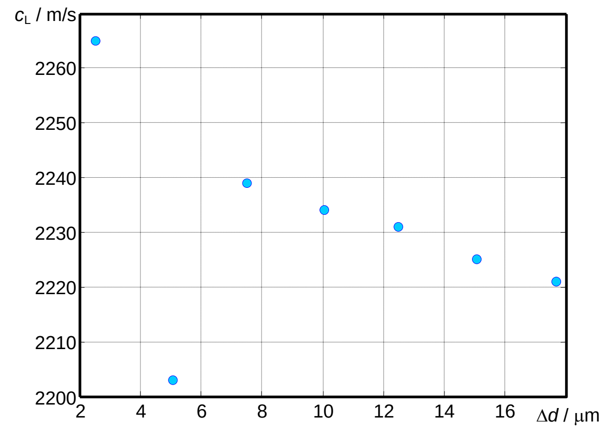

Fig. 3. **Measured velocities of longitudinal waves obtained for different propagation distances at the frequency 1.0 MHz**

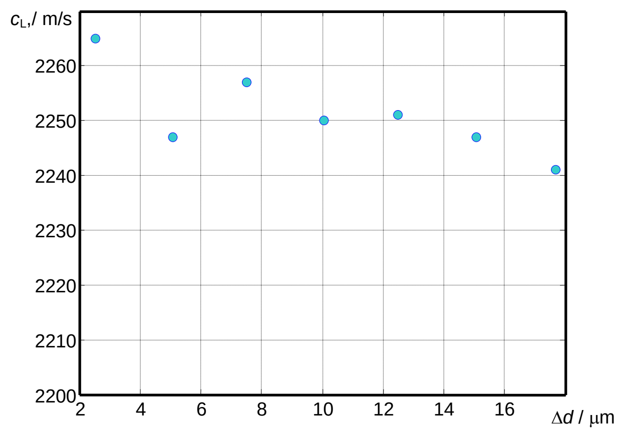

Fig. 4. **Measured velocities of longitudinal waves obtained for different propagation distances at the frequency 3.0 MHz**

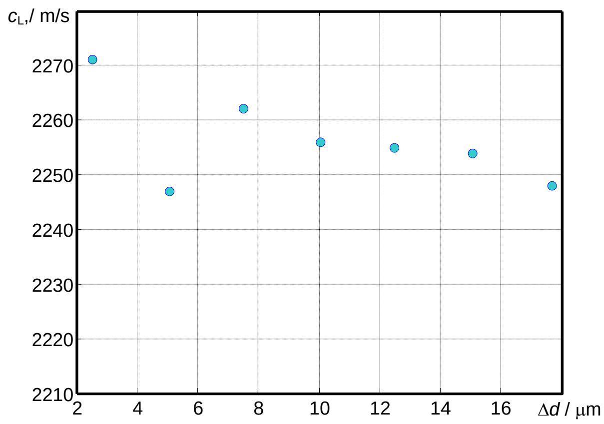

Fig. 5. **Measured velocities of longitudinal waves obtained for different propagation distances at the frequency 5.0 MHz**

The reduction of normalized (corresponding with the amplitude at 2.5 mm distance) peak to peak amplitudes of received signals at the frequency 1.0 MHz and approximated attenuation curve corresponding to this attenuation are presented in Fig. 7. The estimated attenuation coefficient is 0.31 dB/mm. The results of the same investigation at 3.0 MHz and 5.0 MHz frequencies are presented in Fig. 8 and Fig. 9 correspondingly. The attenuation coefficient for ultrasonic longitudinal waves in the tested polyethylene samples at frequency of 3.0 MHz is 0.87 dB/mm and at 5.0 MHz – 1.5 dB/mm.

The dependency of attenuation of ultrasound longitudinal waves propagated in the PE80 type polyethylene on frequency is presented in Fig. 10. This dependency is approximated by 4th order polynomial.

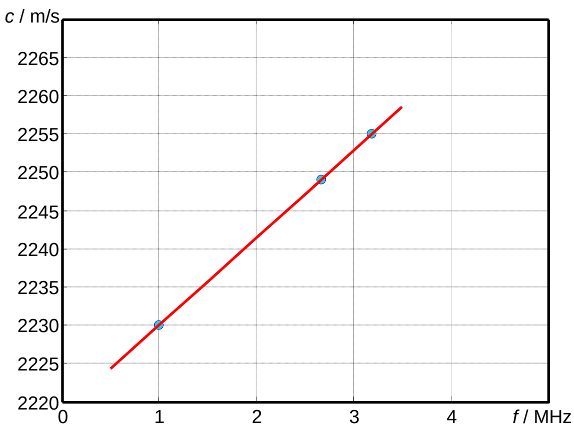

Fig. 6. **The dependence of the velocity of ultrasonic longitudinal waves in the tested PE80 samples on frequency**

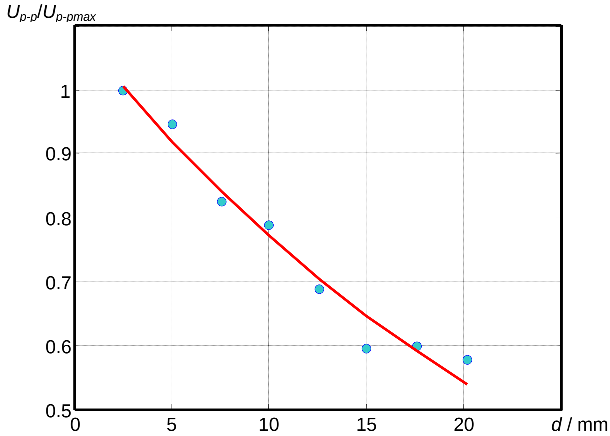

Fig. 7. **The normalized peak to peak amplitudes of the signals received at different distances at the frequency 1.0 MHz and approximated curve of ultrasound attenuation**

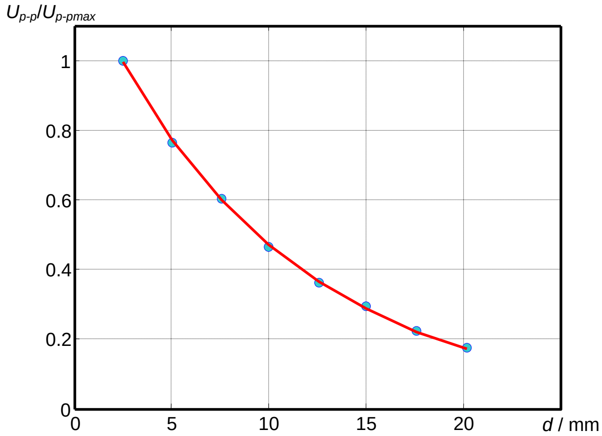

Fig. 8. **The normalized peak to peak amplitudes of the signals received at different distances at the frequency 3.0 MHz and approximated curve of ultrasound attenuation**

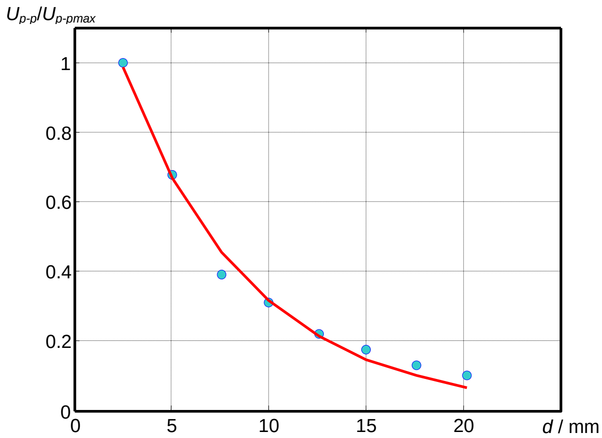

Fig. 9. **The normalized peak to peak amplitudes of the signals received at different distances at the frequency 5.0 MHz and possible approximation curves of ultrasound attenuation**

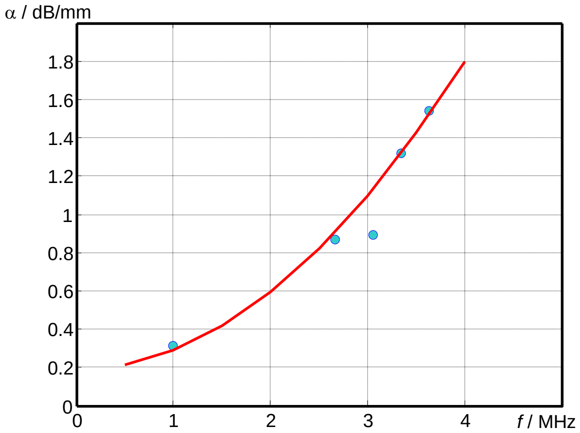

Fig. 10. **The dependency of attenuation of ultrasound longitudinal waves propagated in the PE80 type polyethylene on frequency**

Conclusions

The obtained results demonstrated that velocity of longitudinal waves possess almost linear dependency on frequency at least in frequency ranges from 1MHz to 3.5MHz. The attenuation of longitudinal waves possesses strong dependency on frequency also. The signals with frequencies higher then 4MHz are attenuated strongly and their central frequency is reduced significantly even after several centimetres of plastic.

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Ultragarsinių išilginių bangų greičio ir slopinimo matavimas polietileno bandiniuose

Reziumė

Plastikiniai vamzdžiai yra plačiai naudojami įvairiose pramonės srityse, pagrindinai vandens ir dujų tiekimui. Tokių vamzdžių suvirinimas turi užtikrinti saugią ir ilgalaikę jų eksploataciją, todėl turi būti atliekami suvirinimo siūlių neardomieji bandymai. Pagrindinai šiam tikslui naudojami ultragarsiniai neardomųjų bandymų metodai., Sėkmingam šių metodų taikymui įvertinant specifines fizines–mechanines plastikų savybes būtina tiksliai žinoti jų ultragarsines savybes. Šio darbo tikslas ir buvo galimai tiksliai išmatuoti ultragarsinių išilginių bangų greitį ir slopimą plastikinių vamzdžių medžiagos bandiniuose. Darbe buvo naudojamas skirtingo storio polietileno PE80 bandiniai. Bandinių storiai buvo nuo 2,5 mm iki 20,0 mm. Matavimai buvo atliekami naudojant praėjimo metodą ir 1.0 MHz, 3.0 MHz bei 5.0 MHz kontaktinius keitiklius. Gauti rezultatai parodė tiek išilginių bangų sklidimo greičio, tiek jų slopimo priklausomybes nuo dažnio. Nustatyta, kad sklidimo greitis prie 1MHz yra apie 2030 m/s, o prie 3,5MHz padidėja iki 2060 m/s. Slopinimas tokiam pačiam dažnių diapazone kinta nuo 0.3 dB/mm iki 1.5 dB/mm.

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