ULTRASONIC PROPERTIES OF A NEW LOW ATTENUATION DRY COUPLANT ELASTOMER

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ABSTRACT

Physical properties have been investigated for an new elastomer designed specifically for ultrasonic inspection applications. Unlike dry couplants normally used as an integral part of ultrasonic probes, this elastomer can be applied independently of the probe. Acoustic impedance of the new material is very nearly the same as water and its attenuation coefficient is lower than all other documented elastomers and many plastics. Applications for nondestructive testing include flexible couplant pads, low reverberation dry contact testing of thin wall material and low velocity delay lines.

BACKGROUND

In 1992, with the intent of developing a true dry couplant independent of transducers, the authors began development of an elastomer that can be used like a typical delay-line or like an intervening layer of water but without the inconvenience presented by a liquid. The material was designed specifically with ultrasonic applications in mind and therefore coupling and attenuation factors were considered in its formulation.

Acoustic properties of rubbers and plastics are not extensively covered in nondestructive testing (NDT) literature. A few references exist (vanKrevelen, 1990; Automation Industries circa, 1970; Selfridge, 1985) but of the thousands of polymers relatively few are of practical use in ultrasonic testing for coupling purposes.

High attenuation and dispersion, intrinsic in many of these materials, no doubt accounts for the main limitation of these products in ultrasonics. Most plastics and elastomers have been ignored for ultrasonic transducer delayline and wedge applications, the exceptions being polymethyl methacrylate (PMMA) and polystyrene. Rubbers are even less commonly used as delaylines. Being formulated using a variety of blending agents rubbers can be relatively non-homogenous even on a macroscopic scale; this is particularly noticeable with butyl rubber. The relatively high attenuations of a few plastics and rubbers are listed in Tables 1 and 2. (Note; The number after the @ symbol is the frequency in MHz at which the attenuation applies).

Two of the plastics listed in Table 1, PMMA and polystyrene, are preferred material for contact transducer wedges. These provide several functions in contact testing; a fixed stand-off for thickness testing, fixed angles of incidence for angulated longitudinal and vertically polarised (SV) shear wave testing and as a means of protecting the transducer face from wear, scoring and sometimes overheating. A thin film of water, oil, paste or grease is placed between the test piece and the plastic wedge to facilitate coupling to the test piece. The inconvenience of this fluid for most contact applications of ultrasonic testing is tolerated. However, there are occasions when the intervening fluid is neither tolerable nor practical. Porous materials such as concrete or refractory material would too readily absorb fluids, and greases may be too messy. One of the solutions to this dilemma is the use of so called “dry couplant”.

Table 1: Typical Attenuation Values of Some Plastics Values from Selfridge, IEEE 1985.

Material	Attenuation (dB/mm)
ABS (acrylonitril / butadiene / styrene copolymer)	1.11 @ 5
PMMA - Acrylic (Plexiglas & safety glazing)	0.64 @ 5
Delrin	3.03 @ 5
Nylon(black)	1.60 @5
Polystyrene	0.18 @ 5
PVC (PolyVinylChloride)	1.12 @ 5
Styrene Butadiene	2.43 @ 5

Table 2: Typical Attenuation Values of Some Rubbers Values from Selfridge, IEEE 1985

Material	Attenuation (dB/mm)
Dow Silastic Rubber (45 Durometer)	2.34 @ 4
Dow Silastic Rubber (70 Durometer)	3.37 @ 4
Ecogel 1265	3.34 @ 2
Polyurethane	4.61 @ 4
Pellathane Thermoplastic Urethane	3.20 @ 5

Two more common reference values of attenuation are:

Attenuation in water at 5 MHz is about 0.0055 dB/mm, (ASNT, 1989)

Attenuation in forged chrome-nickel steel is approximately 0.1 dB/mm (Schlengerman, 1983).

Although not always used as such, the wheel probe, described by Krautkramer (1983), is a typical example of dry coupling. Krautkramer described a plywood inspection apparatus used in the USA that utilised a pair of wheel probes arranged for through transmission and requiring no coupling liquid. A simpler adaptation is to place a soft rubber or plastic pad under the probe as described by Szilard (1982). Lynnworth (1989) described early attempts of this technique, made in 1961, using neoprene rubber. Applying some pressure to the probe permits the intervening material to deform slightly and adapt to the surface irregularities on the test object. Dry couplants to date have seen use where frequencies are low, as in concrete and wood testing, where frequencies of down to 40 kHz are used. Such low frequencies ensure the coupling losses in the rubber are negligible. When metals are tested the situation changes. Test frequencies are more typically 1 to 2 MHz and in addition to the appreciable attenuation in the dry coupling medium, reverberations that occur at the interfaces in the pulse-echo mode tend to increase the dead zone.

Testing using horizontally polarized (SH) shear waves is another application where dry pressure coupling is used. Normally SH shear wave coupling is achieved using a non-Newtonian viscous fluid (an example of which is honey); however, moderately high pressures on smooth hard surfaces can facilitate passage of sufficient energy for test measurements without the use of a coupling fluid. Unfortunately the pressures involved for this mode of dry coupling could cause damage to fragile test pieces. Szilard (1982) recommended as much as 150 MPa. in his applications to make birefringence measurements using an AC-cut quartz piezo-element on a polished steel sample.

Jones et al (1986) used two different dry coupling materials in their measurement of the elasticity of ceramics. One was a proprietary material and the other was a latex rubber (surgical glove material)(Blessing, 1994) . In both cases the dry coupling material was very thin, on the order of 0.3 mm. Roberts (1988) utilized a thin film of an unidentified plastic that he vacuum wrapped over his ceramic test pieces to provide intimate contact. As a thin film the plastic's attenuative properties were negligible.

A review of the literature indicates that no dry couplant is actually available on the market. The items mentioned above are either laboratory tools for experimental purposes, proprietary and not marketed, or the material is part of those transducers marketed as "dry couplant transducers". Dry couplant transducers have a thin layer of polymer bonded to the face of the probe. The advantage of some of these is not always clear. An SH dry couplant transducer was compared to a standard type SH transducer and simple 'finger pressure' on both provided no significant signal amplitude difference when they were placed on a metal surface (Hotchkiss, 1994).

DEVELOPMENT AND PROPERTIES OF A NEW POLYMER

The material developed by the authors is based on a blend of isomers of a branched homopolymer. A controlled amount of cross-linking under high temperature and pressure has resulted in a structure that achieves the optimal compromise between attenuation and flexibility that is usually lacking in other dry coupling elastomers. As a result of the controlled cross-linking, the range of temperatures over which the polymer exists in the so-called *rubbery state* (Allcock, 1990) is extended. Proper selection of the cross-link initiator has also allowed the entrapment of a long chain alcohol. This tends to enhance acoustic transmittance. Other additives are used as stabilizers and to increase toughness.

A direct comparison of attenuations in several rubbers was made using a transmit-receive setup in water. Normalizing the water value to 0 dB, 6 mm thick samples were inserted at right angles to the beam. Resultant reductions in signal height are shown in Table 3. Results in Table 3 are obtained using a pair of nominal 10 MHz probes (test at room temperature i.e. 20°C).

Most acoustic properties of the new elastomer were established using through transmission techniques as the acoustic impedance of the elastomer is nearly identical to water. Placing the sample in front of a probe operated in the pulse-echo mode in water would render the material acoustically invisible.

Table 3: Attenuation (dB) of Elastomers Relative to Water (±1 dB)

	Water (Reference)	New Polymer	EPDM (ethylene-propylene copolymer)	Buna Rubber	Viton	Nitrile	Neoprene
Signal Drop (dB)	**0**	**5**	**36**	**42**	**50**	**51**	**51**

Since it is an elastomer, the new dry couplant affords flexibility to accommodate rough surfaces. Its upper useful temperature is about 200° C allowing for elastomeric flexibility over a wide range of temperatures. Attenuation is relatively low for this elastomer and it can transmit frequencies over 25 MHz in the longitudinal mode and easily passes 2 MHz SH shear mode at room temperatures. With such low attenuations, thicknesses of several centimeters can be used between the probe and test piece. This can ensure operation in the far field of the sound beam and also provides added insulation from hot or cold surfaces. The ability to use greater thicknesses of the elastomer for delaylines also eliminates the reverberations that cause the appreciable dead-zone associated with thin polymeric materials typically used on ultrasonic wheel probes and the so-called dry-couplant transducers. This has obvious application in the testing of thin walled materials or when near surface resolution is required.

Microscopic examination of the surface of the elastomer indicates it is relatively unaffected by most organic liquids and aqueous solutions of moderately concentrated acids and alkalis at room temperature.

In Table 4 the attenuation for the longitudinal mode was determined using a simple two thickness technique. The voltage difference of a through transmission signal using a nominal 5 MHz probe pair was compared for samples nominally 15 mm and 25 mm thick. This was used to establish attenuation in dB loss per unit length.

The attenuation coefficient graphed in Figure 1 is the raw data determined according to Read & Dean (1978) and is uncorrected for dispersion and reflection losses.

The following table and figures illustrate some of the features of the elastomer.

Table 4: Tabulation of Properties of the Dry Couplant Elastomer

Property	Value
Density	920 kg/m^3
Longitudinal Velocity	1590 m/s
Shear velocity	800 m/s
Attenuation (long.)	0.28 dB/mm @ 5 MHz
Characteristic Impedance	1.463 MRayls
Poisson's Ratio	0.329
Young's modulus	1.577 x 10^9 Pa
Modulus of Shear	0.593 x 10^9 Pa
Transmission Coefficient of a Longitudinal wave from Water	0.984
Colour	Light blue cast
Opacity	Clear to slightly translucent
Acoustic Birefringence	N/A (isotropic)
Optical Birefringence	Optically active
Acoustic Temperature Dependence (longitudinal velocity)	-2.5 m•s^{-1} •°C^{-1}

Figure 1: Attenuation Coefficient of New Dry Couplant (raw data)

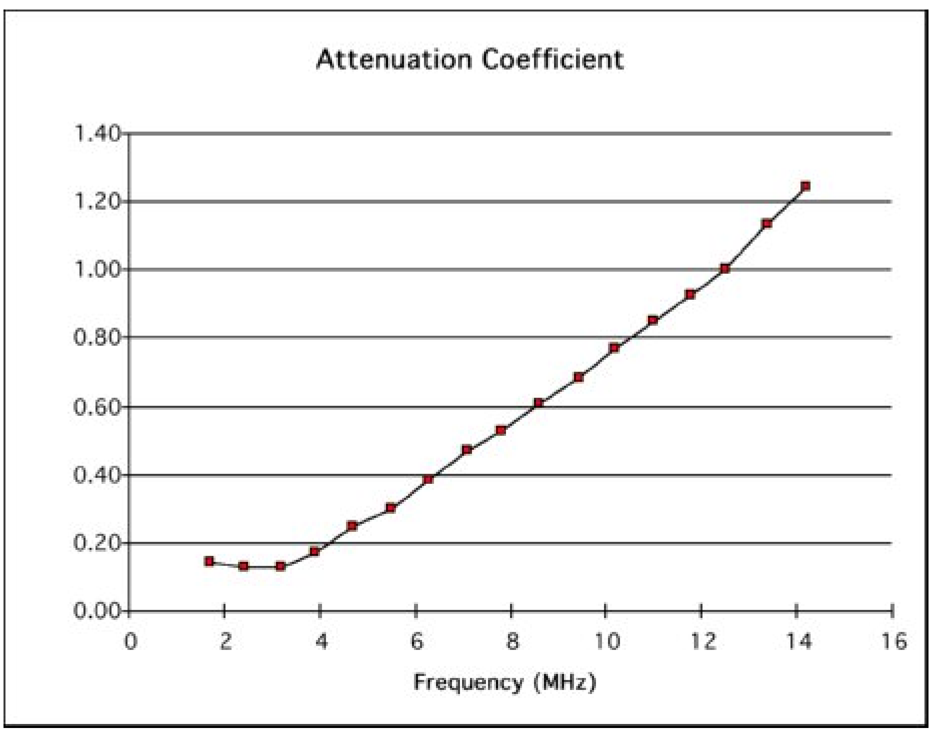
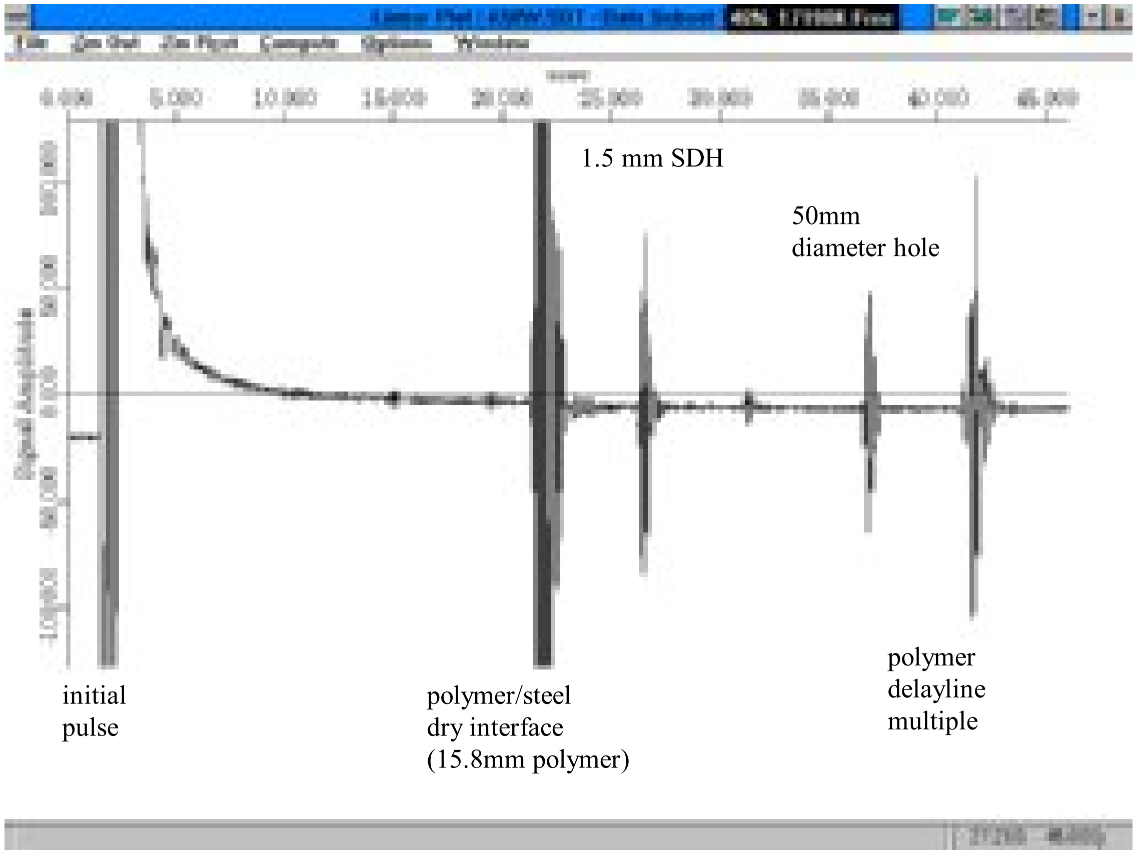


Figure 2: Dry Coupled Probe to IIW Block



Shown in Figure 2 is the response from the 1.5 mm diameter side drilled hole in an IIW block using a 5 MHz compressional mode transducer. The IIW block to elastomer was a dry interface and a standard gel couplant was used for wetting the transducer which was placed on the 15.8 mm thick elastomer coupling material. A load of approximately 2 kg was applied to the transducer.

In Figure 2 the first signal after the initial pulse (polymer/steel interface) occurs at about 21.4 μs. At 26.3 μs a clear signal of the side drilled hole is seen (i.e. 15 mm below the test surface). At about 31.2 μs a weak multiple of the side drilled hole signal is seen. Signals from the 50 mm diameter hole and the delayline multiple occur at 36.6 μs and 41.3 μs respectively.

Figure 3: FFT's Comparing Frequency Shift of New Polymer to Lucite (Perspex)

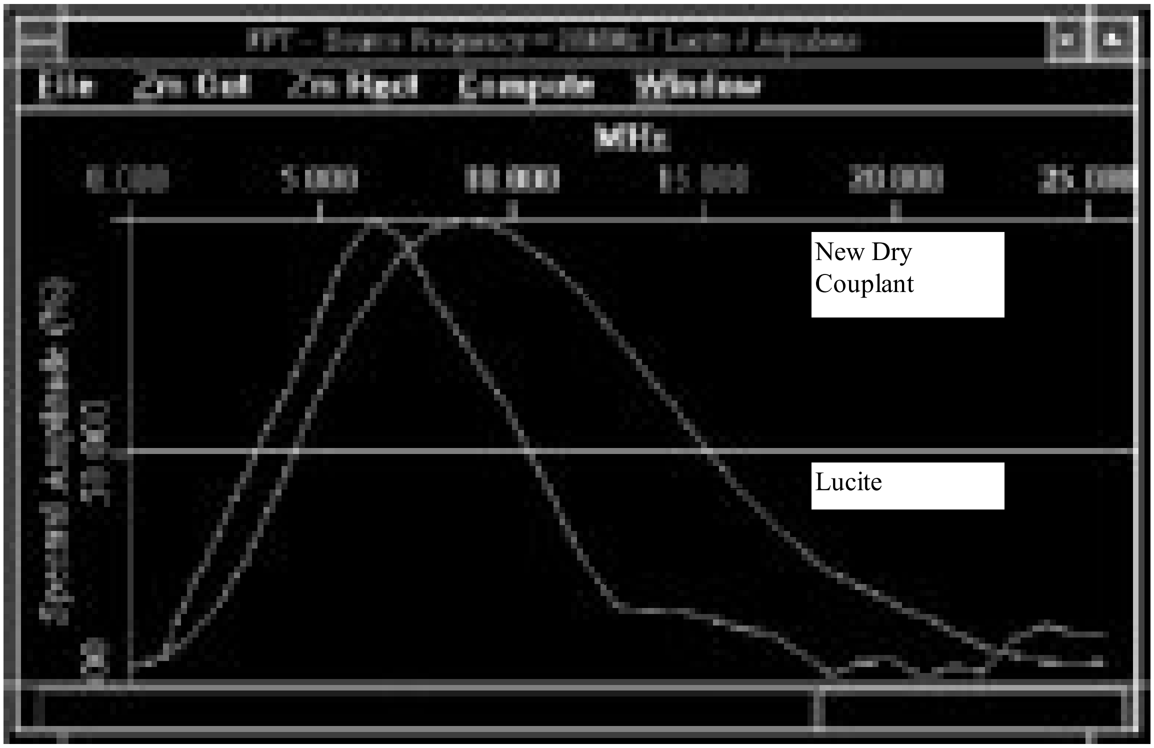


Table 5: Signal Analysis of FFT's in Figure 3

Item	New Polymer	Lucite
Peak Frequency (MHz)	8.730	6.349
Lower Frequency -6 dB (MHz)	3.968	3.175
Upper Frequency -6 dB (MHz)	15.071	11.111
Centre Frequency -6 dB (MHz)	9.524	7.143
Bandwidth (%)	116.67	111.11
Pulse Width -6 dB (μsec)	0.08	0.12

Figure 3 and Table 5 show the frequency changes that result using through transmission (immersion) with a 20 MHz source frequency passing through similar thicknesses. The Lucite sample was 25.3 mm thick and the new polymer sample was 26.3 mm thick. Both samples were tested at 20°C.

In addition to the authors' proposed use as a dry couplant, this material also holds potential for acousto-optical visualization experiments. Effects of stresses and strain can be demonstrated for both compressional and transverse modes.

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References

1. van Krevelen, W., Properties of Polymers, Elsevier Publishing, 1990
2. Automation Industries, Condensed Reference Series for Ultrasonic Nondestructive Testing, vol. 2, Velocity Tables, Automation Industries Inc. Sperry Products Division, circa 1970.
3. Selfridge, A.R., IEEE Transactions on Sonics and Ultrasonics, vol. SU 32, No.3, May 1985, pp 381-387
4. ASNT, Handbook of Nondestructive Testing, vol. 7 second edition, American Society of Nondestructive Testing, 1989
5. Schlengerman, U., The Krautkramer-Branson Booklet, Krautkramer GmbH, 1983
6. Krautkramer, J. and Krautkramer, H., Ultrasonic Testing of Materials, third English edition, chapters 13 & 30, Springer Verlag, 1983
7. Szilard, J., Ultrasonic Testing, Nonconventional Testing Techniques, chapter 9, John Wiley and Sons, 1982
8. Lynnworth, L., Ultrasonic Measurements for Process Control, Academic Press, 1989
9. Jones, M.P., Blessing, G.V., Robbins, C.R., Materials Evaluation, vol. 44 No. 6, June 1986, pp. 859-862
10. Blessing, G.V., Personal communication, 1994
11. Roberts, R.A., Material Evaluation, vol. 46 No. 6, May 1988. pp. 758-766
12. Hotchkiss, F., Personal communication, 1994
13. Allcock, H.R., Lampe, F.W., Contemporary Polymer Chemistry, Prentice Hall, 1990
14. Read, B.E., Dean, G.D., The Determination of Dynamic Properties of Polymers and Composites, chapter 7, Adam Hilger Ltd., 1978