Study the Possibility of Using an Elastomeric Blend as a Plastic Interfacial media in Ultrasonic Transducers

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Abstract:

This work tries to study the using of bromobutyle / butyle elasomeric blends in ultrasonic transducers as a dry plastic interfacial media to inspect porous materials such as concrete and refractory materials which can absorb liquid medias , through the study of acoustic impedance characteristics at interfaces . These characteristics include acoustic impedance , the percentage of energy reflected, dB loss, Power ratios expressions , and Pressure ratios expressions (Reflection Coefficient & Transmission Coefficient). They are studied by using ultrasonic instrument named CSI (type CCT- 4) with 26 KHz frequency . Also, this research try to specify the suitable bromobutyle / butyle blend for immersion inspect through the matching between the acoustic impedance of the blend and that of water. Samples preparation achieved in Babylon Tiers Factory.

Results showed that by increasing bromobutyle ratio in the blend both reflection coefficient and the percentage of energy reflected increased while acoustic impedance and Transmission Coefficient have been decreased. Also, the results show that 20 bromobutyle / 80 butyle is the suitable blend for immersion tests.

Keywords: Ultrasonic Waves , Acoustic Impedance, Rubber Blends.

الخلاصة:

يدرس البحث الحالي إمكانية استخدام خلائط مطاط البيوتيلي – البروموبيوتيلي في محولات الطاقة المستخدمة في تقنيات الفحص بالأمواج فوق السمعية كوسط بيني لدن لفحص المواد المسامية كالكونكريت والمواد الحرارية والتي لها القدرة على امتصاص المواد البينية السائلة وذلك من خلال دراسة خصائص الإعاقة الصوتية عند السطوح البينية .تضمنت هذه الخصائص كل من معامل الإعاقة الصوتي ، نسبة الطاقة المنعكسة ، الطاقة المفقودة ، نسب القوة والضغط على جانبي السطح البيني مثل معاملي الانعكاسية والنفاذية . حُضرت النماذج في مختبرات الشركة العامة لصناعة الإطارات في النجف الاشرف وقد استخدمت معدة CSI(CCT-4) والتي تعمل بتردد قدره 26 KHz لقياس خصائص الإعاقة الصوتية. حاول البحث الحالي أيضا تحديد الخليط المطاطي المناسب لفحوصات الغمر بالماء من خلال موائمة معامل الاعاقة الصوتي للخليط مع نظيره للماء. أظهرت النتائج انه بزيادة نسبة البروموبيوتيل في الخليط المطاطي تزداد كل من الانعكاسية ونسبة الطاقة المنعكسة فيما ينخفض كل من معامل الاعاقة الصوتي ومعامل النفاذية . أظهرت النتائج كذلك إن الخليط المطاطي 80/ 20 (بيوتيل/ بروموبيوتيل) يكون مناسباً لفحوصات الغمر بالماء .

كلمات مفتاحيه: خلائط مطاطية...المعاوقة الصوتيه... الموجات فوق السمعيه

Introduction:

Sound travels through materials under the influence of sound pressure. Because molecules or atoms of a solid are bound elastically to one another, the excess pressure results in a wave propagating through the solid. The acoustic impedance (Z) of a material is the opposition to displacement of its particle by sound and it is defined as the product of its density (p) and acoustic velocity (V). Acoustic impedance is important in [Heller, 2003]:

$$Z = pV \qquad (1)$$

1- the determination of acoustic transmission and reflection at the boundary(interface) of two materials having different acoustic impedances. where at interface , a portion of the sound may be transmitted to the next medium and the remainder reflected back to the first medium [Rouessac and Rouessac, 2004].

2- the design of ultrasonic transducers.

3- assessing absorption of sound in a medium.[Bary and Stanley, 2003].

When the acoustic impedances of the materials on both sides of the boundary are known, the reflection coefficient (R) at an interface between any two materials (RF) can be calculated by the following formula [Sturat , 2007].

$$: R = \left(\frac{z_1 - z_2}{z_2 + z_1} \right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Multiplying the reflection coefficient by 100 yields the percentage of energy reflected (RF) [Olympus, 2010]:

$$RF = \left(\frac{z_1 - z_2}{z_2 + z_1} \right)^2 \times 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where Z_1 & Z_2 acoustic impedances of materials 1& 2.

The ultrasonic waves generated by transducers operate on the principle of piezoelectricity using materials such as quartzite , lithium sulfate [Ginzel & Ginzel, 1994], or various ceramics [Kalpakijian & Schmid, 2003]. An ultrasonic sensor houses a transducer that emits high – frequency , inaudible acoustic waves in one direction when the transducer element vibrates.

Ultrasonic system are used to determine the distance to an object by measuring the time required for an ultrasonic sound wave to travel to the object and return to the source [Senscomp., 2016].

Ultrasound attenuates as it progresses through a medium due to three causes : diffraction , scattering(reflection of the sound in directions other than its original direction of propagation), and absorption (conversion of the sound energy to other forms of energy) [Auld,1990].

The amount of attenuation can play an important role in the selection of a transducer for an application.

The dB loss of energy on transmitting a signal from medium 1 into medium 2 is given by:

$$dBloss = 10\log\left(\frac{4z_1 z_2}{\left(z_2 + z_1\right)^2} \right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

To study the behavior at a boundary , consider a plan wave (incident wave indicated by the symbol i) travelling in material I approaches the boundary . Upon striking the boundary ,part of the energy is reflected back into material I (indicated as r) and part of it is transmitted into material II (indicated as t) [Bary and Stanley, 2003]. The portion of energy transmitted and reflected is a function of the properties of materials I & II .

Pressure ratios expressions can be calculated through the calculations of both the reflection coefficient (R) and the transmission coefficient (T) [Bary and Stanley, 2003]:

$$R = \frac{P_r}{P_i} = \frac{z_2 - z_1}{z_2 + z_1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

$$T = \frac{P_t}{P_i} = \frac{2z_2}{z_2 + z_1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Where : P_r: pressure of reflected wave , P_i : pressure of incident wave, P_t : pressure of transmitted wave.

Values of R&T are employed to calculate both the stress (pressure, amplitude) expressions and the power expressions. Power ratios rather than amplitude ratios are often of greater importance in ultrasonic inspection.

The power expression yield the rate at which the energy is being transmitted by the wave front . For our purpose , power (Pwr) is defined as [Bary and Stanley, 2003] :

$$Pwr = Stress \times Velocity\, at\, a\, point \quad \ldots\ldots\ldots\ldots(7)$$

In a manner similar to that used for the pressure ratios , the power ratios are [Bary and Stanley, 2003] :

$$\frac{Pwr_r}{Pwr_i} = \left[\frac{1-(z_2/z_1)}{1+(z_2/z_1)}\right] \quad \ldots\ldots\ldots\ldots(8)$$

$$\frac{Pwr_t}{Pwr_i} = \left[\frac{4(z_2/z_1)}{(1+(z_2/z_1))^2}\right] \quad \ldots\ldots\ldots\ldots(9)$$

Where Pwr_r: power of reflected wave , Pwr_i: power of incident wave Pwr_t, power of transmitted wave .

Ultrasonic transducer is device that converts electrical energy to mechanical energy in the form of sound , and vice versa . It consists of the following components [Josef and Herbert ,1990]:

1- Active Element : which is piezo or ferroelectric material, converts electrical energy such an excitation pulse into ultrasonic energy.

2- Backing (Damping) : It is usually a highly attenuative . high density material that is used to control the vibration of the transducer by absorbing the energy radiation from the back face of the active element [Heller, 2003, Olympus, 2010]. Usually , a tungsten and epoxy mixture is used [Heller, 2003]. When the acoustic impedance of the backing matches the acoustic impedance of the active element, the result will be heavily damped transducer that displays good range resolution but may be lower in signal amplitude [Olympus, 2010]. If there is a mismatch in acoustic impedance between the element and the backing , more sound energy will be reflected forward into the test material .The end result is a transducer that is lower in resolution due to a longer waveform duration , but may be higher in signal amplitudes or greater in sensitivity [Olympus, 2010].

3- Wear Plate : It is used to protect the transducer element from the environment ; therefore , it must be a durable and corrosion resistance in contact transducer. For immersion , the wear plate has the additional purpose of serving as an acoustic transformers between the active element and the water [Olympus, 2010].

E. A. Ginzel & R. K. Ginzel developed a new elastomer designed specifically for ultrasonic inspection , which can be applied independently of the probe .Porous materials such as concert or refractory materials would too readily absorb fluids and greases may be too messy . One of the solutions to this dilemma is to use the so called " Dry Couplant" [Ginzel & Ginzel, 1994].

Couplant: It is a material (usually liquid) that facilitates the transmission of ultrasonic energy from the transducer into the test specimen. Couplant is generally necessary because the acoustic impedance mismatch between air and solids (i.e. such as the test specimen) is large. Therefore, nearly all of the energy is reflected and very little is transmitted into the test material.

The couplant displaces the air and makes it possible to get more sound energy into the test specimen so that a usable ultrasonic signal can be obtained. In contact ultrasonic testing a thin film of oil, glycerin or water is generally used between the transducer and the test surface. When scanning over the part or making precise measurements, an immersion technique is often used.

In immersion ultrasonic tests of both the transducer and the part are immersed in the couplant, which is typically water (which only allows about 12% of the energy into the steel , and , of course , only 12% of any echoes to pass back across the interface and back to the receiving transducer) [Bary and Stanley, 2003]. This method of coupling makes it easier to maintain consistent coupling while moving and manipulating the transducer and/or the part.

Experimental Work :

Recipes gradients : Elastomeric blends consist of Butyl rubber (IIR) and Bromobutyl rubber (BIIR), in addition to the necessary gradients (table 1).

Table (1) : Gradients of elastomeric blends

No.	Gradient	(pphr)				
1	IIR	100	75	50	25	0
2	BIIR	0	25	50	75	100
3	Zinc Oxide (ZnO)	5.3	5.3	5.3	5.3	5.3
4	Stearic Acid(St. A)	0.93	0.93	0.93	0.93	0.93
5	Carbon Black (N-660)	53.3	53.3	53.3	53.3	53.3
6	Oil	23.2	23.2	23.2	23.2	23.2
7	TMQ	0.85	0.85	0.85	0.85	0.85
8	Sulfur (S)	2.2	2.2	2.2	2.2	2.2
9	TMTD	1.14	1.14	1.14	1.14	1.14
10	MBTS	0.72	0.72	0.72	0.72	0.72

Samples Preparation:

1- Mixing of gradients : By using an open mill ,which contains two roles (the diameter of each one is 150 mm and the length is 300mm), mixing process was accomplish to masticate the gradients until an even and smooth band is formed around the front roller.

The roll mill has the ability to control the gab distance between the rolls at constant rolls temperature (70^{o} C).The mixing operation was executed on two stages: The first one is called master batch consists of rubbers (IIR & BIIR), activators (ZnO & St.A) , antioxidants(TMQ) ,and in the end of this stage carbon black (N-660) and process oil is added in order to have optimum dispersion for the recipe ingredients.

In the second stage ,curing agent (sulfur) , retarders and accelerators (TMTD & MBTS) were added to the previous master batch to prevent pre – vulcanization (scorching) which may occur due to elevated temperature(due to too much heat history).

2- Vulcanization process: By using hydraulic hot press and suitable molds, samples have been cured for certain periods and certain pressures.

3- Sample dimensions: Table (2) shows the dimensions and the vulcanization conditions of the samples used in this research.

Table (2) Sample dimensions and their Vulcanization conditions

No.	Sample Type	Vulcanization Time (min)	Vulcanization Pressure (MPa)	Shape & Dimensions (mm)
1	Specific Gravity	30	40	Disk with 3 mm thickness and 30 mm diameter
2	Ultrasonic Velocity	45	40	Cylindrical rod with 100 mm length and 16 mm diameter

Results and Discussion:

Because both the mass of the atomic particles and the spring constants have different values for different materials, sound will travels at different speeds in various materials. The mass of the particles is proportional to the density of the material, while the spring constant is related to the elastic constants of a material.

Sound velocity affected by many factors, such as density, elasticity and the Poison's Ratio [Heller, 2003].

Figure (1) shows the decrease in ultrasonic velocity with the increase of BIIR ratio in the blend because of the above reasons in addition to the increase of bromo group in the blend .The presence of this big group causes an increase in the free volume. This results in depression of the ultrasonic wave energy.

Acoustic impedance (Z) , also decreases with the increase of the ratio of bromo groups (as shown in figure 2) because of the decrease of both the velocity and the specific gravity of the blend as shown in table 3 . From figure 2 we can also see that the blend with 20BIIR / 80 IIR has acoustic impedance close to that of water (1.47×10^6 kg /m^2.s) ; this blend is suitable for immersion tests.

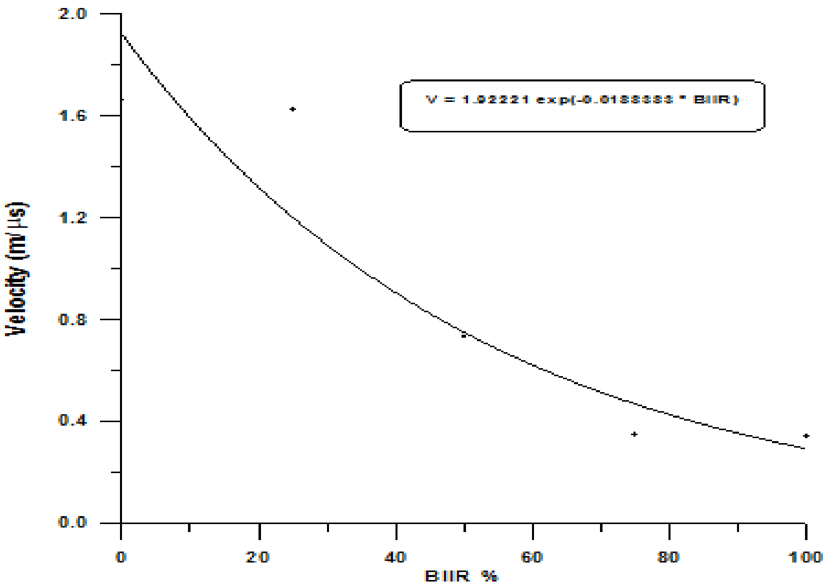

Fig. 1: Ultrasonic Velocity vs. Blend Composition

Table (3): Effect of BIIR ratio upon the characteristics

BIIR	Sp.gr	t (µs)	V_l (m/s)	$Z*10^6$ ($kg/m^2.s$)	RF	R	T	dB loss	Pwr_r / Pwr_i	Pwr_t / Pwr_i
0/100	1.1	48	1.666	1.8326	84.96	0.921	0.07826	-8.227	0.92173827	0.15039855
25/75	1.099	49.2	1.626	1.7869	89.07	0.9236	0.07638	-8.3218	0.92361537	0.14710732
50/50	1.098	109	0.7339	0.8347	93.08	0.9648	0.03518	-11.6	0.96386976	0.07346254
75/25	1.094	230	0.3478	0.3478	96.67	0.9832	0.0167	-14.78	0.98323505	0.03324883
100/0	1.093	234	0.3419	0.34188	96.73	0.9835	0.0164	- 4.86	0.98353227	0.03256426

The amount of the energy that reflected (RF) at the interface between stainless steel type 3XX ($Z = 45 * 10^6$ $kg / m^2.s$) and the blend have been increased because the difference between the values of the acoustic impedances of the two materials increases as shown in figure (3). The difference in Z commonly represents the impedance mismatch.

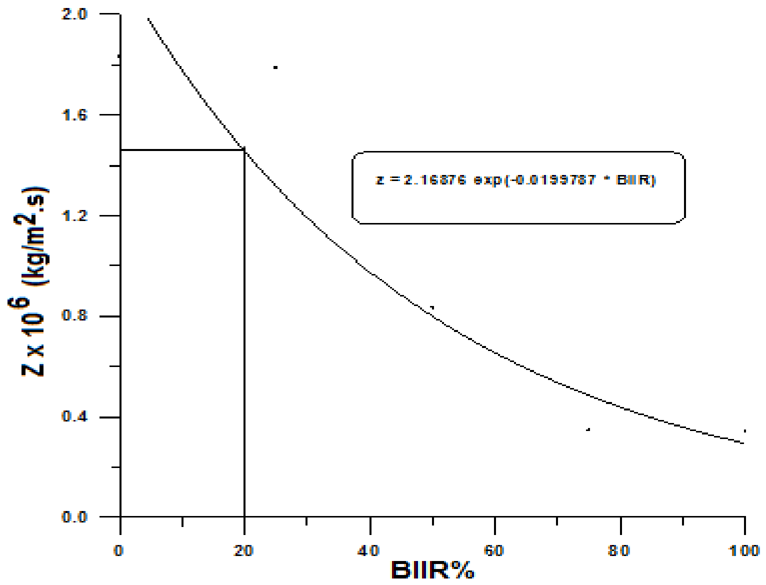

Fig. 2 : Acoustic Impedance vs. Blend Composition

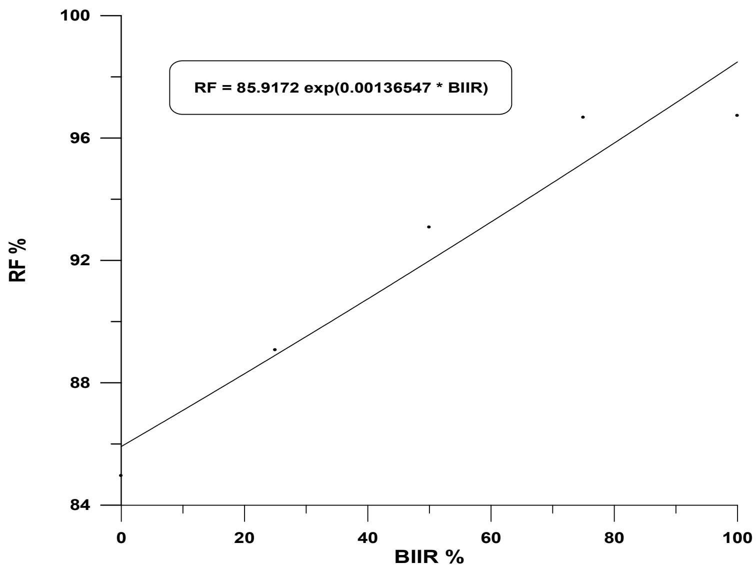

Fig. 3 : Reflected Energy vs. Blend Composition

Figure (4) shows the increase of the values of the reflection coefficient (R) at the interface because of the increase of the reflected portion of the energy (P_r)at the interface .

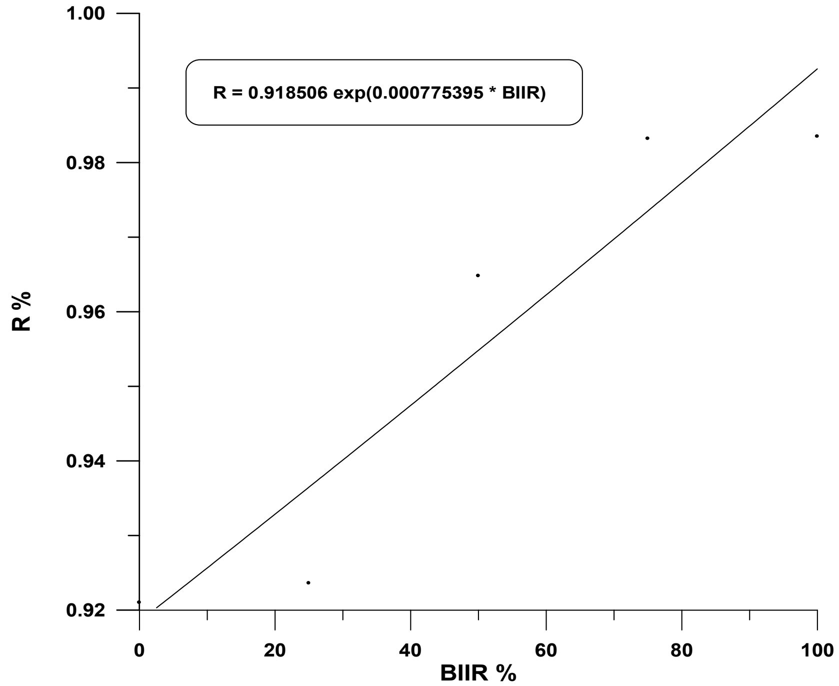

Fig. 4: Reflection (Pressure Ratio Expression 1) vs. Blend Composition

Transmission coefficient (T) has been decreased because of the nature of the blend structure. The new structure plays an important role in the transmit behavior.

Amorphous polymers have a structure specified by a random molecular arrangement. Generally, these polymers are very efficient in their ability to transmit ultrasonic vibrations. Semi-crystalline polymers have regions with orderly molecular arrangement. The molecules of these polymers are spring- like and internally absorb a percentage of vibrations , thus make it more difficult to transmit [Rolf and Ginzel, 2011].

The dB loss has been vary with the composition (as shown in figure 6) because the sound waves reflected from interfaces within the material being tested , and grain boundaries in solids are interfaces that may randomly oriented to the beam [ndt, 2010].

The behavior of both the pressure and the power at the boundary are important in nondestructive inspection. Maximizing the power transfer is important for designing efficient transducer. This is accomplished through proper impedance matching of the transducer ceramic and the receiving material. Where defects are indicated by reflection of ultrasonic energy at a boundary, the degree of impedance mismatch is quite

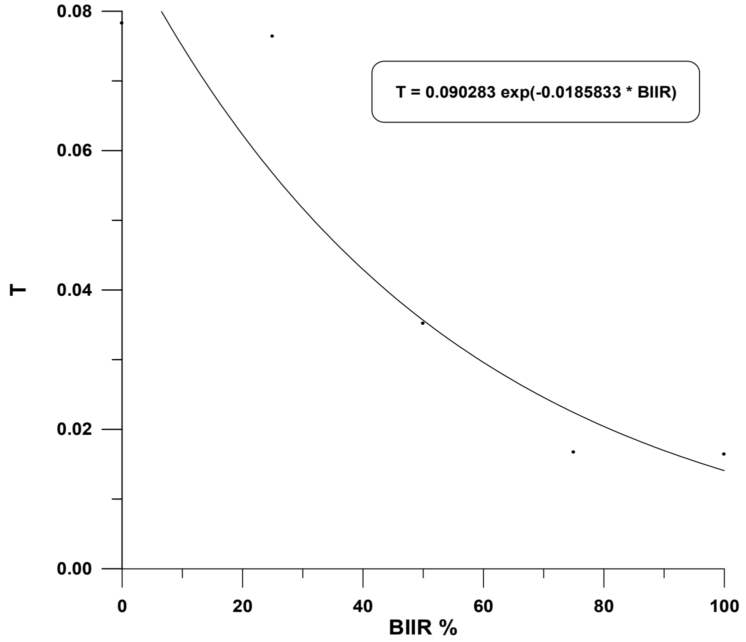

Fig. 5: Transmission (Pressure Ratio Expression 2) vs.
Blend Composition

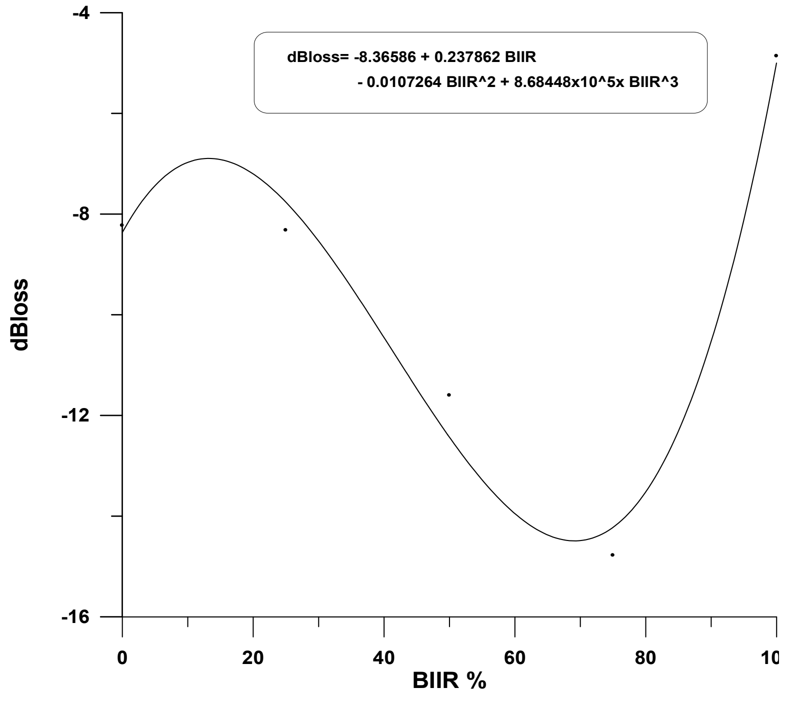

Fig. 6: Energy loss vs. Blend

important in generating the reflected impulse [Mehta , 2007]. There are three situations :

1-When $Z_1 = Z_2$: there is no boundary ; there is no reflection .

2-When $Z_1 >> Z_2$ **:** a metal and fluid , high impedance material radiating into a low impedance material. It simply indicates a change in phase of the reflected wave.

3-When $Z_1 << Z_2$: fluid and material , the results indicate a pressure amplification for a wave transmitted from a low impedance material to one of higher impedance.

Figures (7&8) show the variations of the values of the power expressions depending of acoustic impedances of the two materials.

Table (4) : Pressure ratios & power ratios at boundaries

Ratio	$Z_1 = Z_2$	$Z_1 >> Z_2$	$Z_1 << Z_2$
P_r / P_i	0	-1	1
P_t / P_i	1	0	2
Pwr_r / Pwr_i	0	1	1
Pwr_t / Pwr_i	1	0	0

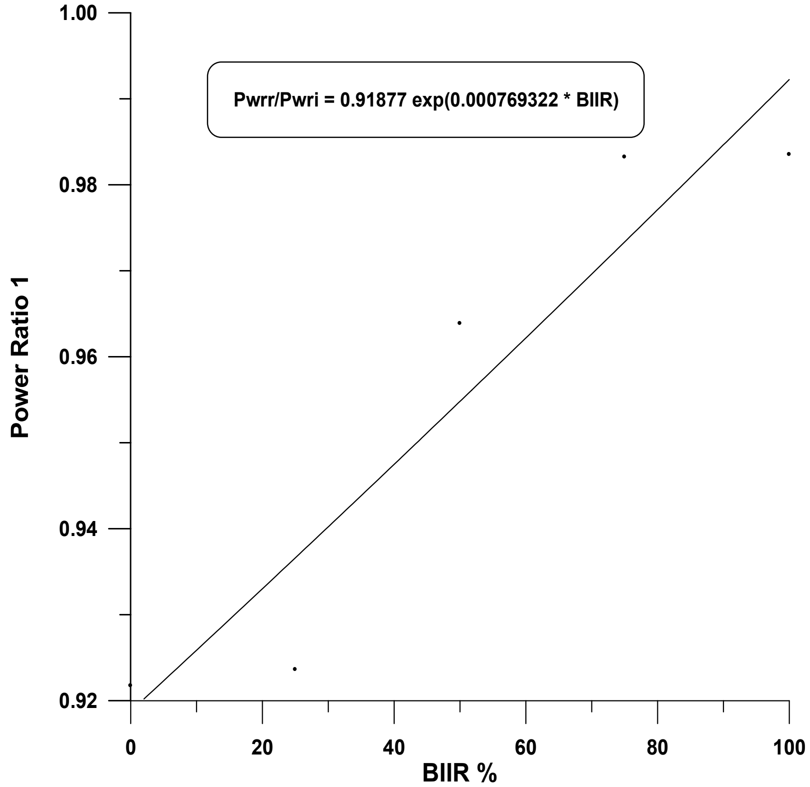

Fig. 7: Power Ratio Expression 1 vs. Blend Composition

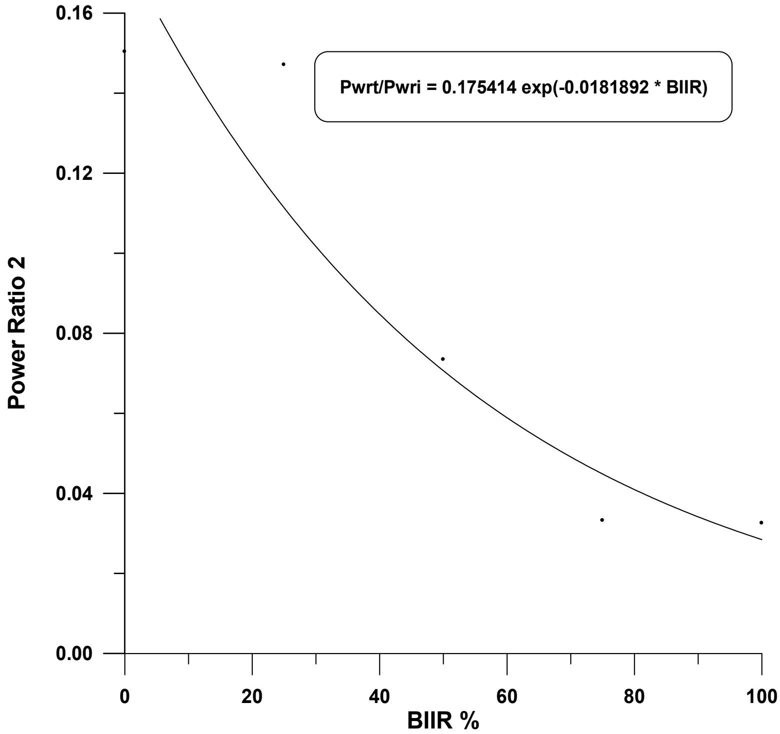

Fig. 8: Power Ratio Expression 2 vs. Blend Composition

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