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Acoustic & Mechanical Properties of Neoprene Rubber for Encapsulation of Underwater Transducers

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Abstract: Acoustical and mechanical properties of specially designed Neoprene rubber compounds were investigated. Three different hardness materials were developed with varied carbon black loading. Sound velocity and density of materials were measured. Acoustic impedance of the materials were evaluated and compared with the acoustic impedance of sea water. Insertion loss and echo reduction of the materials were measured in the frequency range 15 kHz to 85 kHz at room temperature. Insertion loss was less than 2 dB and echo reduction was more than 10 dB through out the frequency range which is suitable for underwater transducer encapsulation material.

Mechanical properties like tensile strength, elongation at break and hardness etc. were investigated which is important for encapsulation materials to withstand hydrostatic or hydrodynamic pressure exerted on it. Materials resistance to hot air ageing and sea water were also conducted in the present study.

Keywords: Acoustically transparent, acoustic impedance, encapsulation, sound speed, insertion loss, echo reduction

1. Introduction

Underwater electro-acoustic transducers are used for transmitting and receiving acoustic signal. Before underwater usage, the electro-acoustic transducers are to be encapsulated with an acoustically transparent material. The encapsulation material will protect the underlying transducers from physical damage and water ingression, while allowing the passage of acoustical signal without significant loss by reflection or absorption.[1]

Rubber components play crucial role in underwater application. They can be used as acoustic windows, sound absorbers, decouplers, anechoic coatings, shielding for acoustic sensors etc.[2,3] Rubber encapsulation protects the transducer elements from heat, oil, weather, sea water & mechanical breakage and also works as electrical insulator. Rubber is the material of choice for underwater acoustic transmission applications as its acoustic impedance can be made to match the acoustic impedance of sea water. Acoustic impedance can be modified over a broad range for rubber, both by polymer selection and compound formulation. At boundary, there is no reflection of sound waves if the acoustic impedance of the two media is equal.

The present paper describes the development and investigation of three different materials based on Neoprene rubber with varied carbon black loading which can be used for encapsulation of underwater electro-acoustic transducers. Neoprene rubber is considered to make acoustically transparent material as it has superior chemical and physical response to adverse environment. These properties include excellent weather & abrasion resistance, very good resistance to flame, fuel, water, heat, ozone & oxidation and since it is a polar rubber, it offer very good dielectric properties. [2,4] W-type neoprene rubber is selected for this development work as it has high tensile properties with better storage stability and cure adjustment can be made to suit a wide range of processing conditions.[4] Care was taken while design the rubber compounds such that the rubber materials housing the sensor elements or transducer are transparent to sound signals in the desired frequency range and have sufficient strength to withstand the hydrostatic / hydrodynamic pressure exerted on it. Rubber compounds are specially designed for electrical insulation resistance properties to avoid short circuit. Mechanical properties of rubber compounds were studied as per ASTM standards. The acoustical transparency of rubber material was studied by measuring the percentage of sound transmitted through & reflected from the sample of material immersed in water. Ageing resistance to hot air and sea water were also conducted for better service life of the materials.

2. Experimental

2.1 Rubber compound preparation

Neoprene rubber W-type, i.e, Skyprene B-30 was compounded with combinations of metallic oxides, like zinc oxide and magnesium oxide along with accelerator, which functions as the vulcanizing agent. Antioxidants are included in the base compounds to ensure good ageing properties. This formulation also include essential modifiers (stearic acid) required to obtain satisfactory handling properties. SRF carbon black (N770) has been added for improving mechanical properties like tensile strength, hardness, abrasion and for improved electrical insulation properties etc. Different dosage of carbon black (25, 50 and 75 phr) has been taken to prepare 50, 60 and 70 shore-A hardness compound i.e C-50, C-60 & C-70. Naphthenic process oil (Elasto-541) was added for physical softening of compound.

2.2 Acoustical Properties

2.2.1 Sound Velocity

The velocity of sound is the distance traveled during unit time by a sound wave propagating through an elastic medium. Ultrasonic Thickness Gauge (Model 25HP Plus of OLYMPUS, USA make) was used to measure the sound velocity of materials. Ultrasonic non-destructive testing introduces high frequency sound waves into a rubber sheet or test object to obtain information about the object without altering or damaging the material. In this instrument, the time of flight or the amount of time for the sound wave to travel through the sample sheet is measured. Based on thickness of material as input data and time of flight data, the sound velocity is calculated directly by the instrument as follows.[5]

$$T = c t_s / 2 \qquad (1)$$

c = Material sound velocity
T= Material thickness
t_s= Time of flight

2.2.2 Acoustic Impedance

The acoustic impedance is a measure of the acoustic behavior of a material. It is the opposition to displacement of its particles by sound waves[12]. Acoustic impedance (Z) of a material is defined as the product of its density (ρ) and sound velocity (c).

$$Z = \rho c \qquad (2)$$

Z = Acoustic impedance
ρ = Material density
c = Material sound velocity

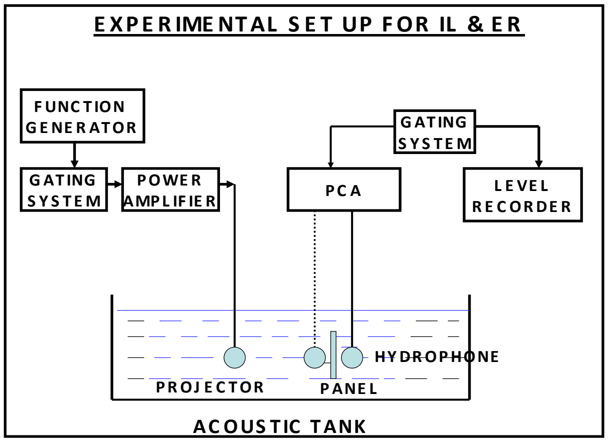
It is important to determine the transmission and reflection of sound waves at the boundary of two materials having different impedances. The boundary between two materials of different acoustic impedances is called acoustic interface. When sound strikes an acoustic interface at normal incidence, some amount of energy is transmitted through the sample and some amount of energy absorbed & reflected by the sample. But at the boundary, there is maximum transmission of sound energy with minimum reflection of sound waves if the acoustic impedance of the two media is equal.

Acoustic impedances of the materials were calculated and matched with acoustic impedance of sea water (1.55 M-Rayls at 20°C). Acoustic Impedance of sea water is calculated as

$$\begin{aligned} Z = \rho c &= 1030\ \mathrm{Kg.m^{-3}} \times 1500\ \mathrm{m.s^{-1}} \\ &= 1.55 \times 10^{6}\ \mathrm{Kg.m^{-2}.s^{-1}} \\ &= 1.55\ \text{M-Rayls} \qquad (3) \end{aligned}$$

2.2.3 Insertion Loss & Echo Reduction

For acoustical transparency measurements, a sheet of size 300mm x 300mm x 6mm was made in a compression moulding press. The rubber sheet was tested in an acoustic tank by panel method. Standard transducers (projector and hydrophone) ITC-1042 has used for acoustic measurement. A high frequency pulse of short duration was applied to a standard transducer (projector), that sends out a beam of sound waves into the liquid (water) and picked up by a standard hydrophone (receiver) placed in the acoustic path. The specimen (rubber sheet) was introduced into the sound path and from the relative amplitudes measured on the oscilloscope before and after introduction of the sample between the transmitter and receiver, the insertion loss and echo reduction are calculated. Measurements are carried out in the frequency range of 15 kHz to 85 kHz. The schematic view of the experimental set-up for measurement of insertion loss and echo reduction is shown below.



Insertion loss measurement

Sample sheet was positioned inside the water at a depth of 2 meter from the top. Both Projector and Hydrophone were also positioned inside water at 2m depth. Standard hydrophone is positioned just behind the sample to receive the transmitted signal. The projector transmits the sound waves and the transmitted sound waves through the test sample were received by the standard hydrophone. Then the test sample was removed from the acoustic path and the sound waves transmitted by projector were measured by the hydrophone. This is the direct or incident sound pressure. Insertion loss is calculated as follows;

Insertion Loss, dB = 20 log (Incident sound pressure / Transmitted sound pressure). (4)

Echo reduction measurement

It is a measure of how much incident sound pressure is reduced after reflection. Here the hydrophone is placed in front of the test sample. The projector transmits the sound waves and the reflected sound waves from the test sample were measured by the hydrophone. Echo reduction is calculated as follows;

Echo Reduction, dB = 20 log (Incident sound pressure / Reflected sound pressure) (5)

2.3 Mechanical properties

The tensile testing of the materials were carried out in a Universal Testing machine (Hungta, Taiwan) according to ASTM D 412 a test method using dumb-bell shaped specimen at a cross-head speed of 500 mm/min at room temperature (25±2°C). Hardness was measured as per ASTM D-2240 standard with the help of Universal Hardness tester (Baressis, Germany).

2.4 Environmental Resistance

Materials resistance to Liquid-B (Iso-octane 70% & Toluene 30% by volume) and resistance to Sea water were studied as per ASTM D-471 standard. Materials were soaked in the reference liquid and kept inside the hot air oven at 40°C temperature. After different time intervals, the materials were removed from reference liquid and its change in volume and change in weight were measured.

2.5 Accelerated Ageing

2.5.1 Hot air ageing

Materials resistance to hot air were studied as per ASTM D-573 standard. Test samples were kept in a hot air oven at reference temperature. After different time intervals, samples were removed from oven and its change in properties like tensile strength, elongation at break & hardness were measured.

2.5.2 Sea water ageing

Materials resistance to sea water was studied. Test samples were immersed in sea water and kept in a hot air oven at reference temperature. After different time intervals, samples were removed from oven and its change in properties like tensile strength, elongation at break & hardness were measured.

3. Results and Discussion

3.1 Acoustical Properties

3.1.1 Sound Velocity & Acoustic Impedance

Initially sound velocity and density of materials were measured. Then acoustic impedance of materials were calculated by multiplying sound velocity and density data. All the values are shown in the Table-1.

Table 1 Sound velocity, density and acoustic impedance for the developed materials.

Material	Sound Velocity, c ($m.s^{-1}$)	Density, ρ ($Kg.m^{-3}$)	Acoustic Impedance Z = ρc ($Kg.m^{-2}.s^{-1}$ or Rayls)
C-50	1620	1360	$2.20x10^6$

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C-60	1660	1410	$2.34x10^6$
C-70	1700	1440	$2.45x10^6$

As the carbon black loading increases i.e, from 25 phr to 75 phr, density of material as well as sound velocity increases, because with increase of carbon black loading, bulk modulus of elasticity of the material increases which is directly proportional to the sound velocity of materials i.e, sound travels faster through media with higher modulus of elasticity and/or lower density[16].

As both sound velocity (c) and density (ρ) of materials increases with increase of carbon black loading, materials acoustic impedance (Z) also increases as it is a product of materials density (p) and sound velocity (c). Acoustic impedance of three materials C-50, C-60 & C-70 are $2.20x10^{6,}$ $2.34x10^6$ and $2.45x10^6$ $Kg.m^{-2}.s^{-1}$ respectively and are very close to the acoustic impedance of sea water i.e, 1.55×10^6 $Kg.m^{-2}.s^{-1.}$ So at the boundary, there will be maximum transmission of sound waves with minimum reflection and absorption.

3.1.2 Insertion Loss, dB

Insertion loss was measured for all the three materials in the frequency range of 15 kHz to 85 kHz at room temperature. Table 2 and Figure 1 show the effect of frequency on insertion loss of the materials.

Table 2 Insertion loss of materials with frequency.

Frequency (kHz)	Insertion Loss (dB)		
	C-50	**C-60**	**C-70**
15	1.74	2.49	2.76
20	0.56	0.82	2.49
25	1.4	0.59	1.8
30	0.29	1.16	0.75
35	1.87	1.02	2.14
40	0.44	0.35	3.52
45	1.51	1.08	3.69
50	0.27	1.02	1.86
55	0.42	1.27	3.46
60	0.51	1.12	2.23
65	1.07	1.26	0.74
70	0.99	1.58	1.72
75	1.45	0.94	1.68
80	1.3	1.09	3.52
85	0.12	1.41	0.97

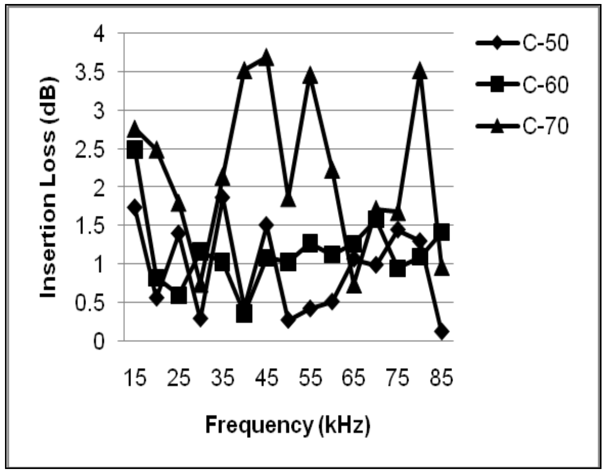

Fig.1. Insertion loss of materials with frequency.

Insertion loss values for C-50 and C-60 are less than 2 dB throughout the frequency range of 15 kHz to 85 kHz which is suitable for acoustically transparent materials. But the Insertion loss values for C-70 are 0.74 to 3.69 dB in the frequency range of 15 kHz to 85 kHz which are higher than other two materials. This may be due to the comparatively higher acoustic impedance value of C-70 materials as compared to acoustic impedance of sea water.

3.1.3 Echo Reduction, dB

Echo reduction or reduction in sound reflection was measured for all the three materials in the frequency range of 15 kHz to 85 kHz at room temperature. Table 3 and Figure 2 show the effect of frequency on echo reduction of the materials.

Table 3 Echo reduction of materials with frequency.

Frequency (kHz)	Echo Reduction (dB)		
	C-50	**C-60**	**C-70**
15	18.66	17.5	7.35
20	11.12	18.58	7.95
25	14.80	13.53	8.29
30	22.76	11.39	7.95
35	20.00	12.56	7.51
40	12.04	12.42	5.19
45	12.64	10.16	3.52

50	19.78	10.88	9.54
55	11.52	10.76	11.48
60	10.71	10.41	10.88
65	12.08	10.07	9.29
70	18.75	11.39	7.04
75	11.68	13.97	6.02
80	15.29	11.61	8.20
85	13.54	10.20	8.78

Properties	Materials		
	C-50	C-60	C-70
Tensile strength (Mpa)	16.6	17.85	13.71
Elongation at break (%)	610	560	330
Hardness (Shore-A)	52	59	70

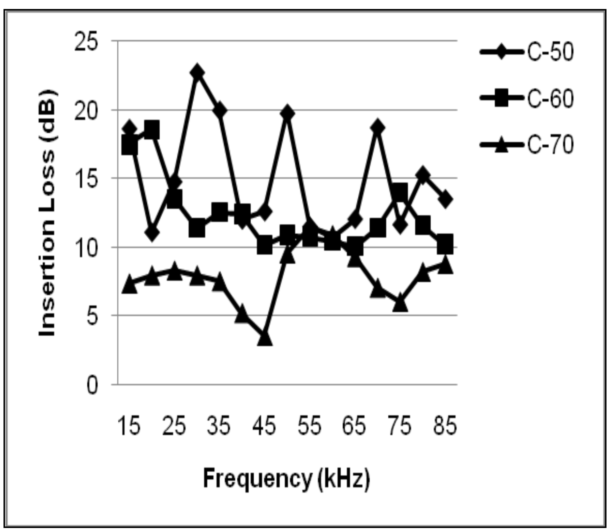

Fig. 2. Echo reduction of materials with frequency

Echo Reduction values for C-50 are 10.71 to 22.76 dB & for C-60 are 10.07 to 18.58 dB in the frequency range of 15 kHz to 85 kHz which are suitable for acoustically transparent materials. But the Echo reduction values for C-70 are 3.52 to 11.48 dB in the frequency range of 15 to 85 kHz which is lower than other two materials. This is due to the comparatively higher acoustic impedance value of C-70 material as compared to acoustic impedance of sea water.

Based on insertion loss and echo reduction values, C-50 and C-60 are suitable for acoustically transparent application in the frequency range of 15 kHz to 85 kHz.

3.2 Mechanical properties

Tensile strength, elongation at break and hardness of three materials are shown below in the Table 4.

Table 4 Mechanical properties of developed materials.

Tensile strength of the material increases up to 50 phr carbon black loading and then decreases. This is due to the fact that in the initial stage the interaction between polymer chain & carbon black is more and at the higher loading the interaction between carbon black is more compared to that of interaction between polymer chain and carbon black which leads to decrease in tensile strength. Elongation at break for all is above requirements and decreases with increase of carbon black loading. Hardness of compound increases with carbon black loading, it is due to agglomeration of more percentage of carbon black which gives more stiffness and hence more resistance to indentation.

3.3 Environmental Resistance

All the three materials were immersed in Liquid-B and kept in hot air oven at 40°C for 24 hours. Then change in volume were measured. In the same way all the three materials were immersed in sea water and kept in hot air oven at 40°C for 24 hours. Then change in weight were measured. The results are summarized in Table-5.

Table 5. Environmental Resistance properties of developed materials

Properties	Materials		
	C-50	C-60	C-70
Change in volume (%) in liquid-B	30.67	28.08	24.20
Change in weight (%) in sea water	0.31	0.28	0.26

Change in volume of the materials in liquid-B decreases with the increase of carbon black loading. It is due to the increase in hardness of material, which gives more stiffness and hence chances of penetration of oil are less. i.e, less swelling & hence better oil resistance. Change in weight of the materials in sea water decreases with the increase of carbon black loading.

3.4 Accelerated Ageing

3.4.1 Hot air ageing

Test samples were kept in a hot air oven at 70°C temperature for 7 days. Their change in properties like tensile strength, elongation at break & hardness were measured and depicted in the Table 6.

Table 6. Hot air ageing properties of developed materials

Properties	Materials		
	C-50	**C-60**	**C-70**
Change in tensile strength (%)	-4.15	-4.30	-6.25
Change in Elongation at break (%)	-7.50	-12.50	-11.50
Change in Hardness (Shore-A)	+2	+1.7	+2

Change in properties like tensile strength, elongation at break & hardness are well within the requirements. From hot air ageing value it is clear that, these materials will resist the deterioration of physical properties with time caused by oxidative & thermal ageing.

3.4.2 Sea water ageing

Test samples were immersed in sea water and kept in a hot air oven at 70°C temperature for 7 days. Their change in properties like tensile strength, elongation at break and hardness were measured and given in Table-7.

Table 7. Sea water ageing properties of developed materials

Properties	Materials		
	C-50	**C-60**	**C-70**
Change in tensile strength (%)	-2.45	-3.10	-3.25
Change in Elongation at break (%)	-10.0	-11.0	-11.5
Change in Hardness (Shore-A)	+2	+2	+2.1

Change in properties like tensile strength, elongation at break & hardness are well within the requirements. From sea water ageing value it is clear that, these materials will resist the deterioration of physical properties with time caused by sea water ageing.

3.5 *Electrical properties*

Insulation Resistance of all the three materials were measured with 500 Volt Megger and the values are more than 500 M-ohm which is suitable for underwater transducer encapsulation applications.

4. Conclusions

The following conclusions can be made from the present work.

1. Three different hardness materials (C-50, C-60 and C-70) were made based on neoprene rubber.
2. Acoustical, mechanical, electrical and environmental resistance properties of these materials were investigated.
3. Materials acoustic impedance was calculated from materials sound velocity and density. Acoustic impedance is 2.20×10^6 to 2.45×10^6 $Kg.m^{-2}.s^{-1}$ which is close to the acoustic impedance of sea water (1.55×10^6 $Kg.m^{-2}.s^{-1}$).
4. Materials insertion loss and echo reduction were measured in the frequency range of 15 kHz to 85 kHz. Insertion loss values for C-50 and C-60 material was less than 2 dB and echo reduction values was more than 10 dB through out the frequency range, which is suitable for underwater transducer encapsulation material.

5. For C-70 materials though the properties like mechanical, electrical and environmental resistance are good but both insertion loss and echo reduction values are poor. So this C-70 material is not suitable for underwater electro-acoustic transducer encapsulation material.

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Literature Cited

(1) Thomas Ramotowski and Kirk Jenne. NUWC XP-I Polyurethane –Urea: A new acoustically transparent encapsulant for underwater transducers and hydrophones. Oceans 2003 proceedings, Vol-1, Page-227-230.

(2) Rodger N. Capps. Influence of carbon black fillers on acoustic properties of polychloroprene (neoprene) elastomers. J. Acoust. Soc. Am. 1985, 78, 406.

(3) C.M.Roland. Naval applications of elastomers. Rubber Chemistry & Technology, July-2004, Vol-77, No-3, pp 542-551.

(4) J.A. Brydson Rubbery Materials and their Compounds

(5) Technical notes of Panametrics, Inc. www.panametrics.com

(6) H.G.Im, K.R.Ka and C.K.Kim. Characteristics of Polyurethane blends with Poly(acrylonitrile-co-butadiene) rubber as an encapsulant for underwater sensor devices. Ind. Eng. Chem. Res. 2010, 49, 7336-7342.

(7) Peter H. Mott, C. Michael Roland and Robert D. Corsaro. Acoustic and dynamic mechanical properties of a polyurethane rubber. J. Acoust. Soc. Am. 111(4), April 2002.

(8) Corley M. Thompson and William L. Heimer. Relationship between acoustic properties and structure of Polyurethanes. J. Acoust. Soc. Am. 77(3), March 1985.

(9) Donald P. Massa. An overview of electro-acoustic transducers. Massa Products Corporation.

(10) R. N. Capps, C. N. Thompson and F. J. Weber. Handbook of sonar transducer passive materials. NRL memorandum report 4311, October 30, 1981, Naval Research Laboratory, Washington D.C.

(11) V.B. Pillai, "Rubber in underwater sensor technology", Naval Physical & Oceanographic Laboratory, Kochi, India

(12) V.B. Pillai, "Studies on rubber composition as passive acoustic material in underwater electro-acoustic transducer technology and their ageing characteristics", Naval Physical & Oceanographic Laboratory, Kochi, India

(13) T.R.Natarajan, K.Trinath, V.V.S. Bhaskara Raju and A.V.N.R. Rao. "Effect of carbon black filler on the acoustical properties of rubber for underwater applications", Naval Science & Technological Laboratory, DRDO, Visakhapatnam, AP, India

(14) V.Srinivassan, S.A.Janaki and K.K.Parambil, "Characterisation and classification of underwater acoustic materials", Naval Physical & Oceanographic Laboratory, Kochi, India

(15) K.Trinath, "Sensor materials and their applications", Naval Science & Technological Laboratory, DRDO, Visakhapatnam, AP, India

(16) www.engineeringtoolbox.com/speed-sound