The effect of polymer coating on acoustic transducer material - design, analysis & optimization

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Abstract – This paper aims at design the Acoustic transducer to withstand high pressures. Transducer is layered with Natural rubber, Neoprene, Nitrile rubber and Polyurethane and selects the suitable polymer among them in order to withstand high pressures. In general under sea water 1bar pressure increases to every 10 meters depth. Hence the performance of transducer varies with depth of water and pressure. The function of Acoustic transducer is receiving and sends the acoustic signal. Different types of transducers made of PZT's (lead zirconate-titanate) and Ceramics etc are available in the market for underwater applications. Because of good acoustical properties Clay poled ceramic material has been used for transducer instead of PZT's. As per ASTM D 3182 standards Polymer material specimen is taken and tensile strength test is conducted, and generates the stress versus strain curve. The uniaxial test data is necessary for Hyper Elastic curve fitting to evaluate the C01, C10 constants. CATIA V5R20 software is used for modeling and ANSYS 17.0 version is used for analysis. Mate lab program is used for determining stresses at other thicknesses. Among the four polymers Nitrile rubber is suitable for Acoustic transducer design to withstand high pressures.

Key words: Decoy, CATIA, ANSYS, Clay poling

Introduction

Acoustic transducer is a device which converts acoustic signals into electrical signal and vice versa. For underwater applications use the acoustic transducer [1] piezoelectric ceramics, polymers, single crystals and composites are the four varieties of materials used widely as acoustic transducer material [2] The strong forces and the ability to work at a high operation frequency make the piezoelectric suitable for acoustic applications [3] Crack propagation in a typical structural ceramic is accompanied by acoustic emission. two types of emission are detected, first is caused by slow growth of the fracture-initiating flaw and second is occurs due to bulk stressing [4] aligning all of the individual dipole moments in the same single direction by the process called poling. Poling is a process of subsequent heating above the Curie temperature by the application of electric field and cool below the Curie temperature. Each dipole will feel a torque in the electric field if it is not parallel to the field lines produced, and so is turned to that direction [5] rubbers and polyurethane is used as insulation material to withstand high pressures. The polyurethanes (PU) foams are widely used as insulating and core materials [6] Rubber composites have wide applications such as seals, hoses, soles and gloves. The incorporation of carbon black largely increased the tensile strength, tear strength, tensile modulus and abrasion resistance of rubber compounds [7]

EXPERIMENTATION

The test method used to evaluate the tensile properties of Neoprene, Natural rubber and Nitrile rubber. The specimen is taken according to ASTM D 3183 standards.

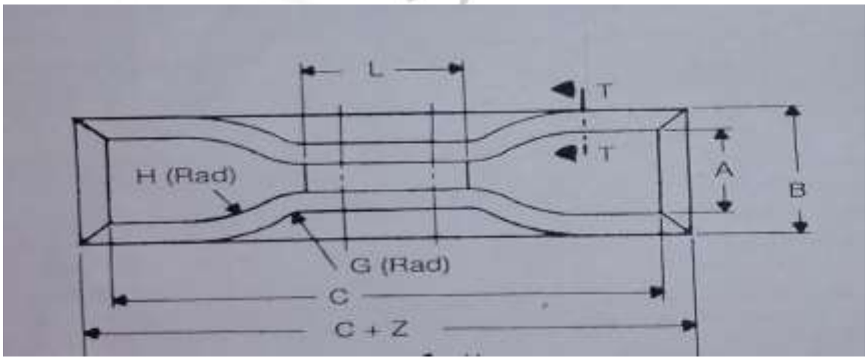
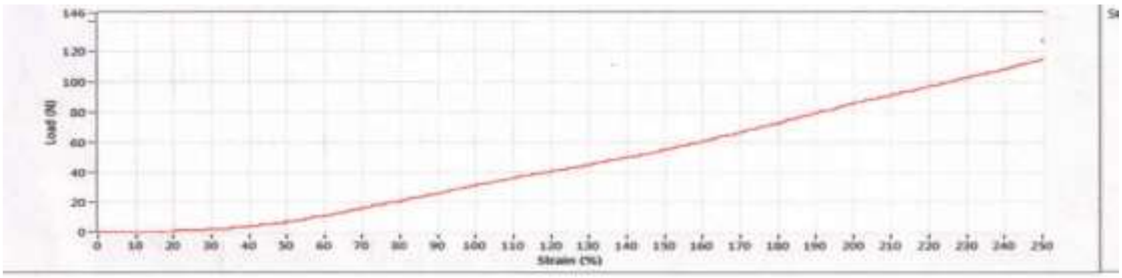
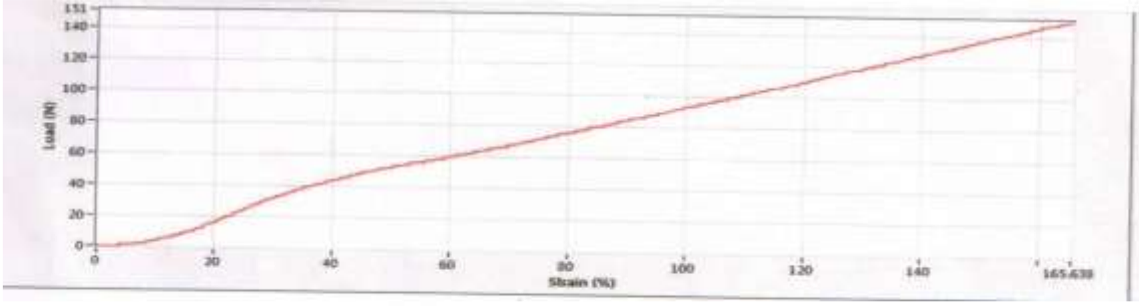


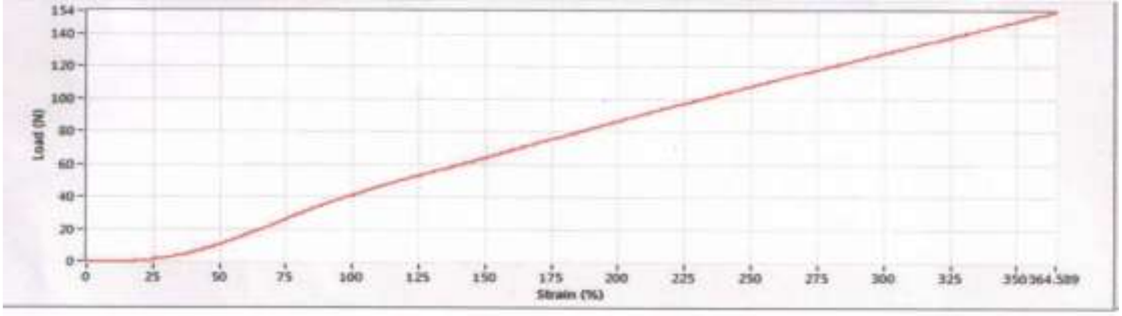
Figure 1.1: Rubber specimen according to standards



Graph 1.2: Nitrile rubber load (N) vs Strain (%) Graph



Graph 1.3: Neoprene rubber -load (N) vs Strain (%) Graph



Graph 1.4: Natural rubber -load (N) vs Strain (%) Graph

Calculations:

Calculate the tensile stress at any specified elongation as follows:

$$T_{(xxx)} = F_{(xxx)} / A$$

Where:

$T_{(xxx)}$ = tensile stress at (xxx) % elongation, MPa
$F_{(xxx)}$ = force at specified elongation, MN and
A = cross-sectional area of unstrained specimen, m^{2}.
$Y_{(stress)} = F_{(Y)} / A$
Where
$Y_{(stress)}$= yield stress, that stress level where the yield point occurs, MPa
$F_{(Y)}$ = magnitude of force at the yield point, MN
A = cross-sectional area of unstrained specimen, m^{2}.

Evaluate the yield strain as that strain or elongation magnitude, where the rate of change of stress with respect to strain, goes through a zero value.

Calculate the tensile strength as follows:

$TS = F_{(BE)} / A$

Where:

TS = tensile strength, the stress at rupture, MPa
$F_{(BE)}$= the force magnitude at rupture, MN , and cross-sectional area of unstrained specimen, m^2

Calculate the elongation as follows:

$$E = 100 [L - L_{(0)}] / L_{(0)}$$

Where:

E = the elongation in percent
L = observed distance between bench marks on the extended specimen, and
$L_{(0)}$ = original distance between bench marks

Natural rubber		Nitrile rubber		Neoprene	
Load (N)	Strain %	Load (N)	Strain %	Load (N)	Strain %
0	0	0	0	0	0

IJEDR

6.67	40.55554	3.75	36.6652	31.5	14.31675
13.33	54.44444	6.875	49.58135	44	19.998
20	64.44443	13.125	63.3308	56	25.452
26.67	73.88887	20	77.91355	67	30.4515
33.33	83.88888	39.6875	118.3286	84	38.178
40	97.77776	59.0625	157.4937	105	47.7225
60	140	75.78125	188.3258	131	59.5395
80	184.1667	98.4375	223.3244	159	72.2655
100	229.4444	113.4375	247.9068	177	80.4465
120	277.7778	146	474.825	191	86.8095
140	326.1111			115	109.5238
154	362.402			136.3	129.8095
				151	463.450

Table: Load vs Strain % values

Natural rubber	Nitrile rubber	Neoprene
0	0	0
0.501428	0.290878	2.368065
1.002105	0.533276	3.307773
1.503533	1.018073	4.209893
2.004962	1.55135	5.036837
2.505638	3.07846	6.31484
3.007067	4.58133	7.89355
4.5106	5.878161	9.848143
6.014133	7.635549	11.95309
7.517667	8.799061	13.30627
9.0212	11.32485	14.35874
10.52473		8.645316
11.57721		10.24658
		11.35168

Table: Stress (mm)

MODELING OF ACOUSTIC TRANSDUCER

Modeling of transducer has done using CATIA V5 R20 software.

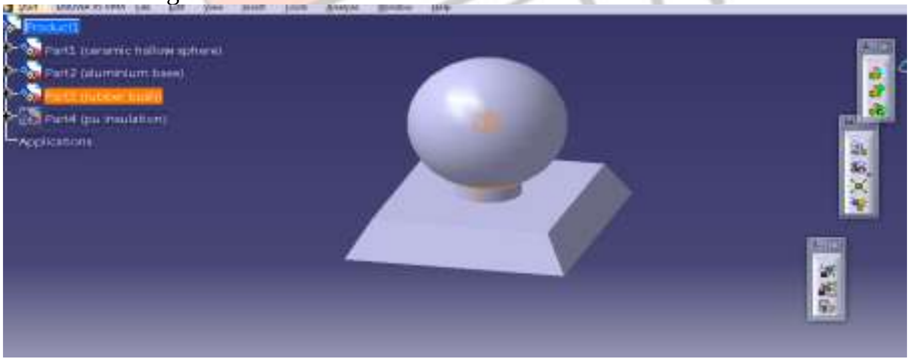


Figure 1.5: Model of Acoustic transducer.

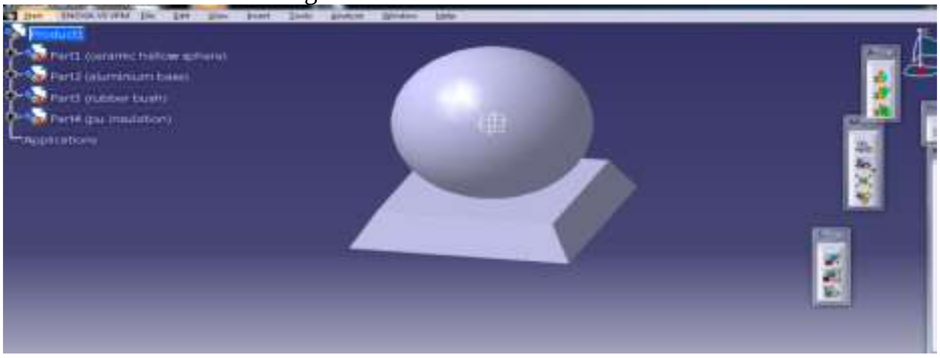


Figure 1.6: Model of Acoustic transducer layered with rubber

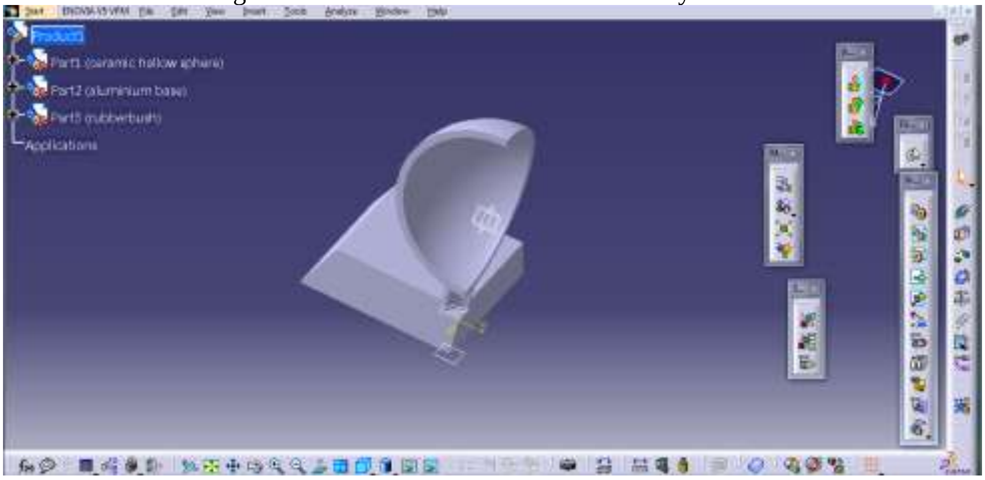


Figure 1.7: Quatre part of Acoustic transducer

To do static analysis in ANSYS APDL as axi symmetric problem it can be modeled as quarter part of the transducer.

Parameter	Value
Inner diameter of hallow sphere	69 mm
Outer diameter of hallow sphere	71 mm
Height of alumina block	20 mm
Width of alumina block	100 mm
Taper angle of alumina block	26.56^0

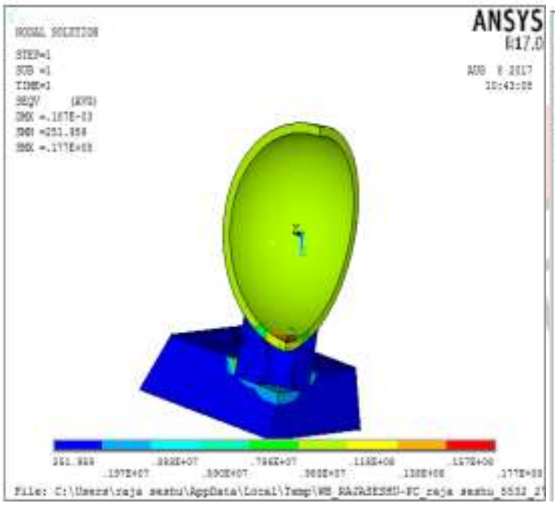
Table: Design parameters of Acoustic Transducer

Finite element analysis

Static analysis is carried out to determine the maximum stresses at different depths using ANSYS APDL 17.0 version.

ANSYS results

Stress on transducer at 200, 300, 400 ant failure (246) meters depth



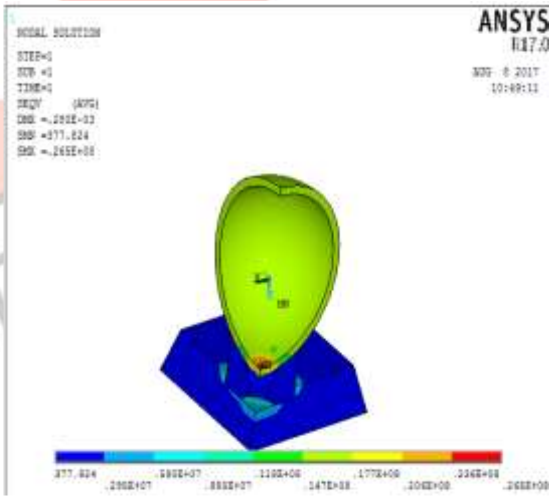


Figure 1.5: Transducer at 200 m depth Figure 1.9: Transducer at 300 m depth

Stresses obtained in the Acoustic transducer at 2MPa, 3MPa, 4MPa and 2.6MPa for 200 meters, 300 meters, 400 meters and failure depth 260 meters respectively are shown in Figures 1.8, 1.9 1.10 and 1.11

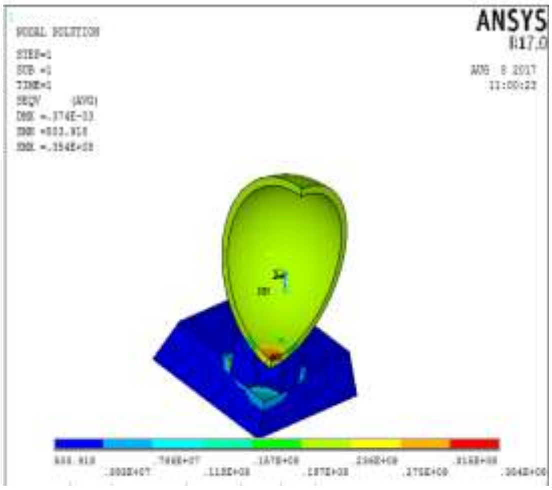


Figure 1.10: Transducer at 400 m depth

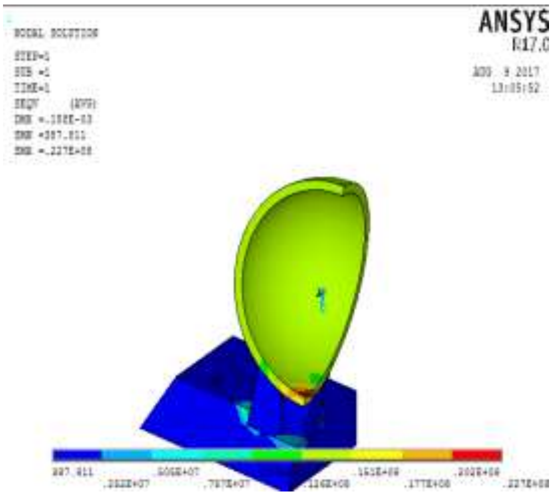


Figure 1.11: Transducer at Failure (248m) depth

2 mm Polymer layer Insulation

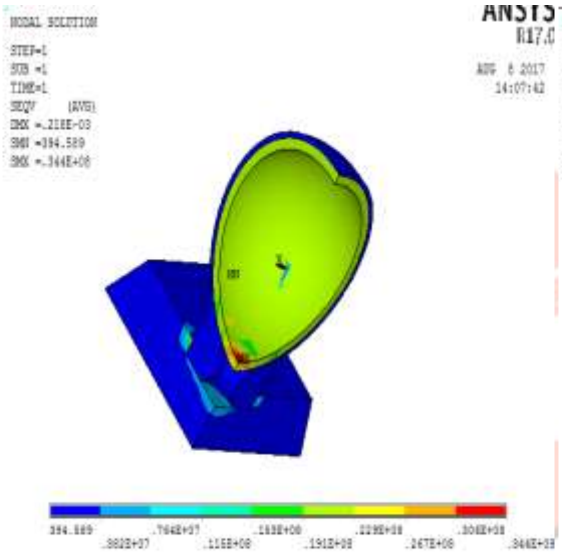


Figure 1.12: 2 mm Neoprene rubber insulation

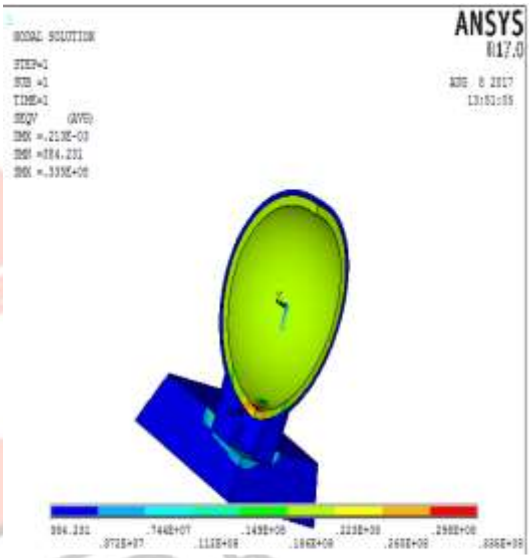


Figure 1.13: 2 mm Nitrile rubber insulation

2mm thick layer of Neoprene, Nitrile, Natural rubber and Polyurethane insulation is provided to transducer for reducing stresses and the result is shown in 1.12, 1.13, 1.14 and 1.15figures.

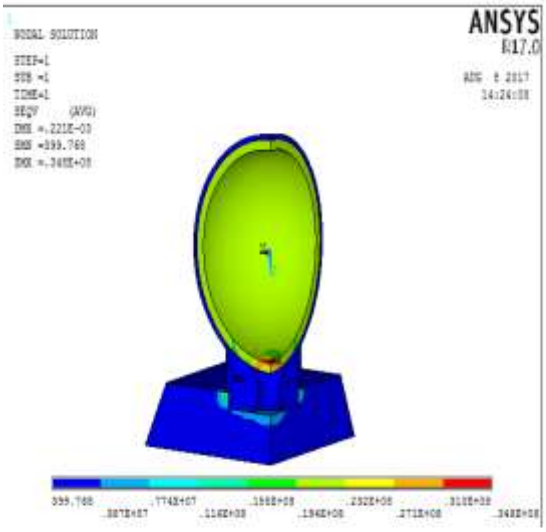


Figure 1.14: 2 mm Natural rubber insulation

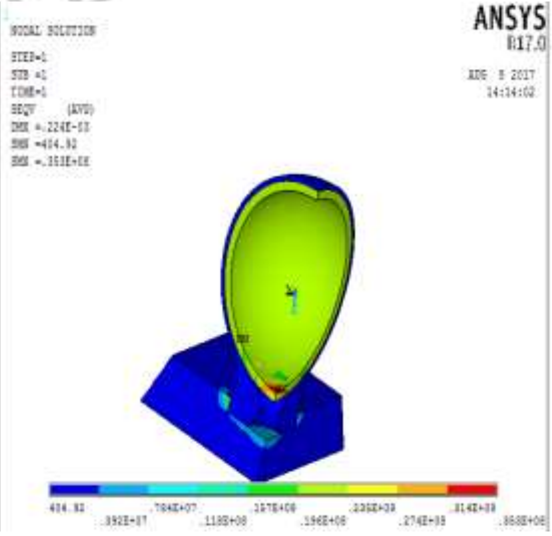


Figure 1.15: 2 mm Polyurethane insulation

4mm Polymer layer Insulation

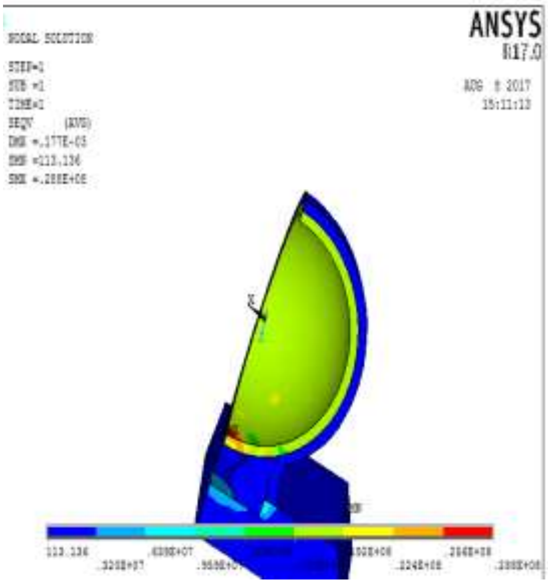


Figure 1.16: 4 mm Neoprene rubber insulation

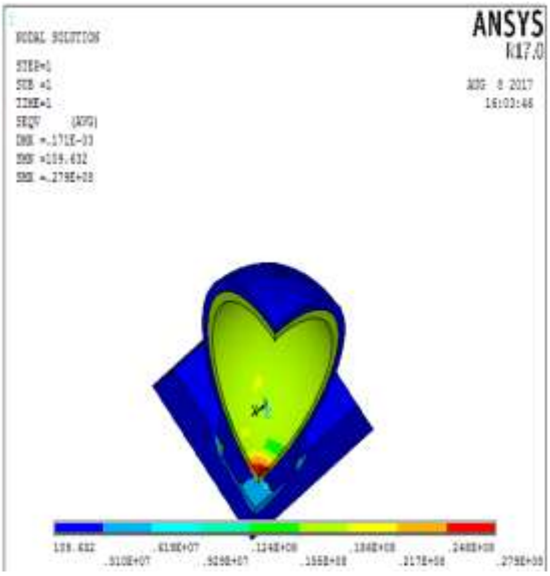


Figure 1.17: 4 mm Nitrile rubber insulation

4mm thick layer of Neoprene, Nitrile, Natural rubber and Polyurethane insulation is provided to transducer for reducing stresses and the result is shown in 1.16, 1.17, 1.18 and 1.19 figures.

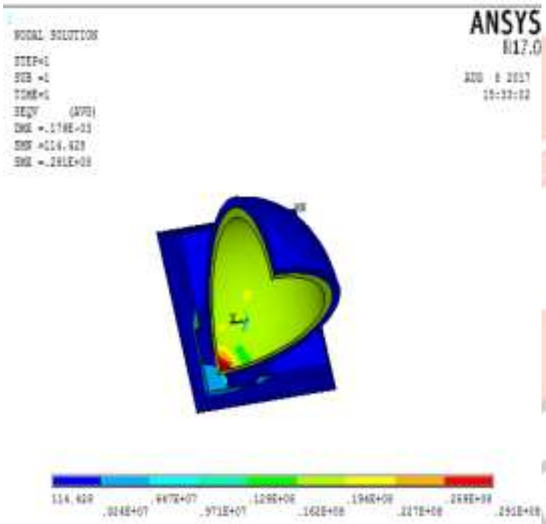


Figure 1.18: 4 mm Natural rubber insulation

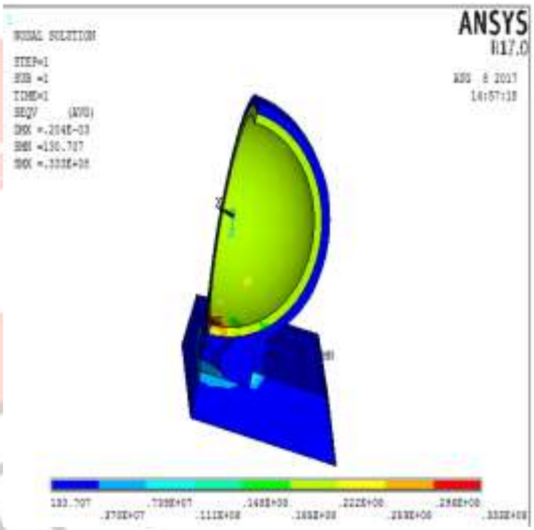


Figure 1.19: 4 mm Polyurethane insulation

5 mm Polymer layer Insulation

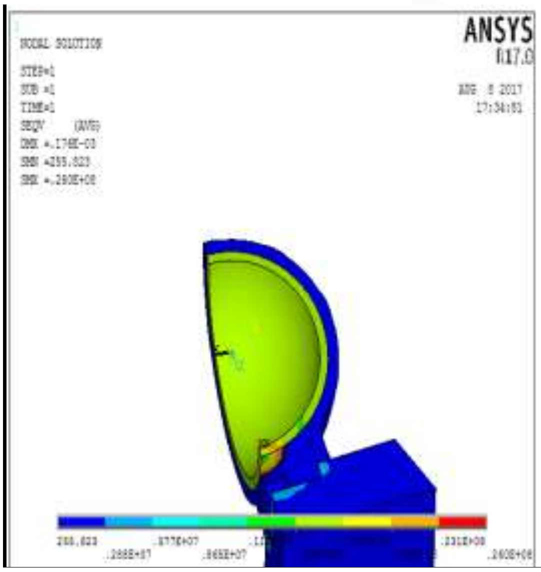


Figure 1.20: 5 mm Neoprene rubber insulation

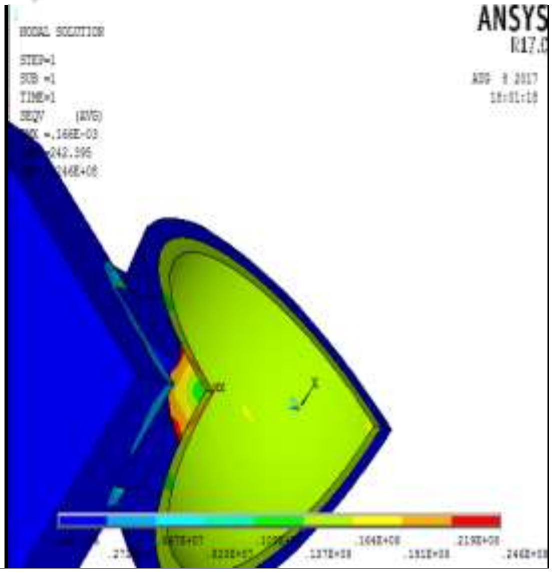


Figure 1.21: 5 mm Nitrile rubber insulation

5mm thick layer of Neoprene, Nitrile, Natural rubber and Polyurethane insulation is provided to transducer for reducing stresses and the result is shown in figures.

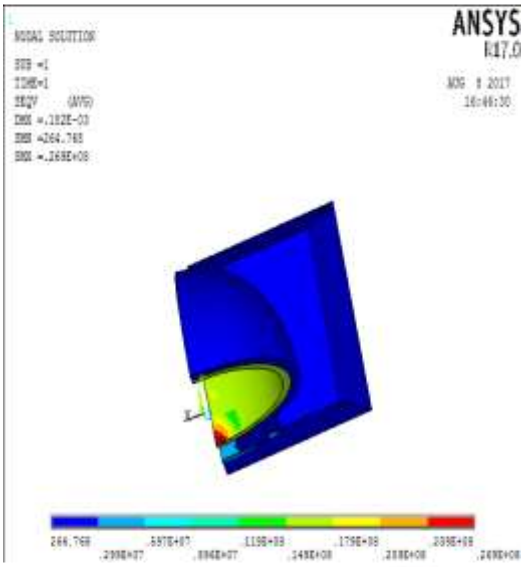


Figure 1.22: 5 mm Natural rubber insulation

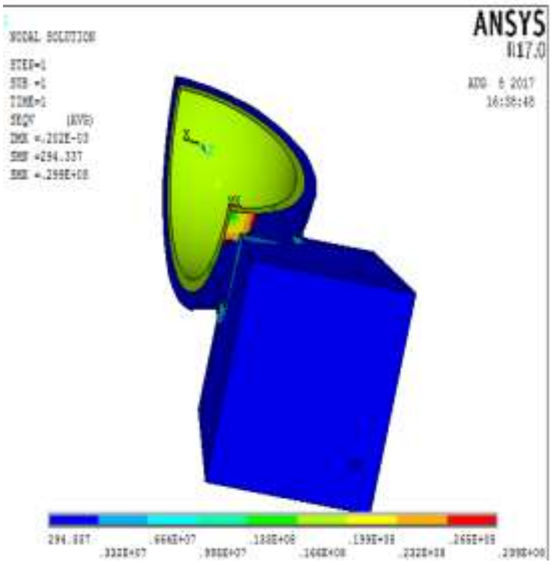


Figure 1.23: 5 mm Polyurethane insulation

6 mm Polymer layer Insulation

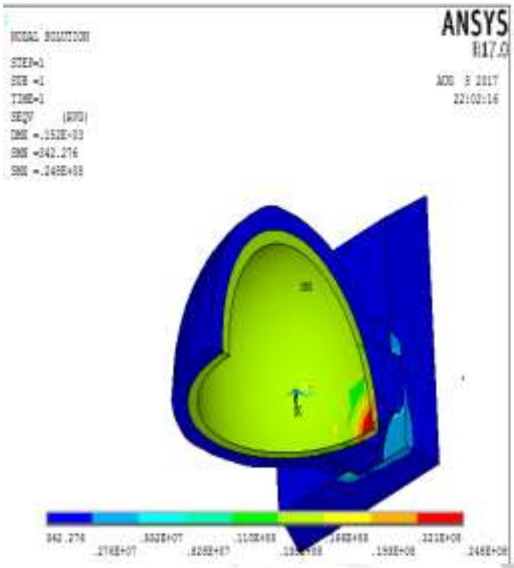


Figure 1.24: 6 mm Neoprene rubber insulation

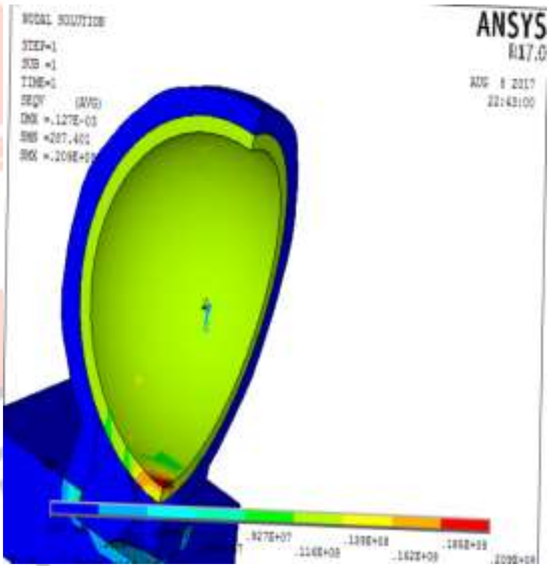
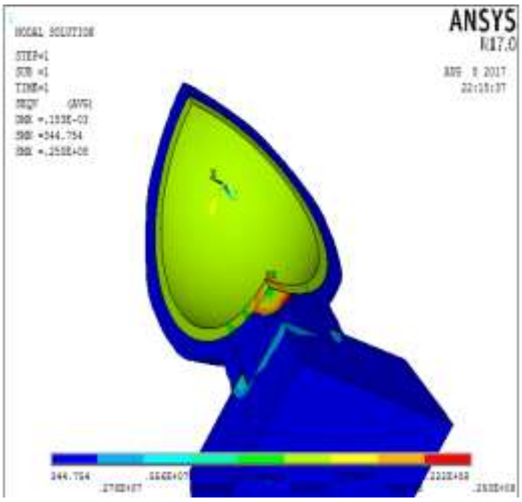


Figure 1.25: 6 mm Nitrile rubber insulation

6mm thick layer of Neoprene, Nitrile, Natural rubber and Polyurethane insulation is provided to transducer for reducing stresses and the result is shown in 1.24, 1.25, 1.26 and 1.27figures. At 6mm thickness of Nitrile rubber we obtained the stress below the proof stress.



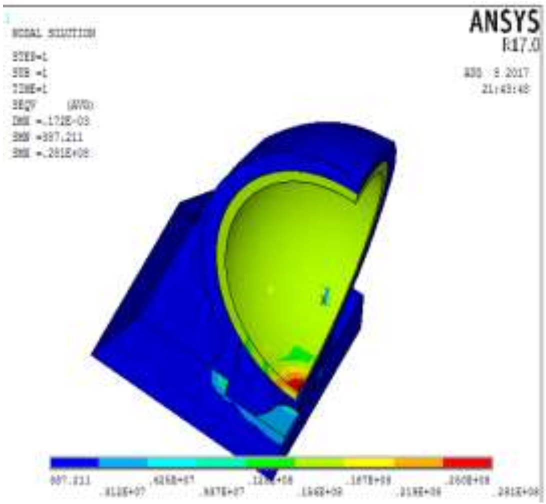


Figure 1.26: 6 mm Natural rubber insulation Figure 1.27: 6 mm Polyurethane insulation

8.1.6 7 mm Polymer layer Insulation

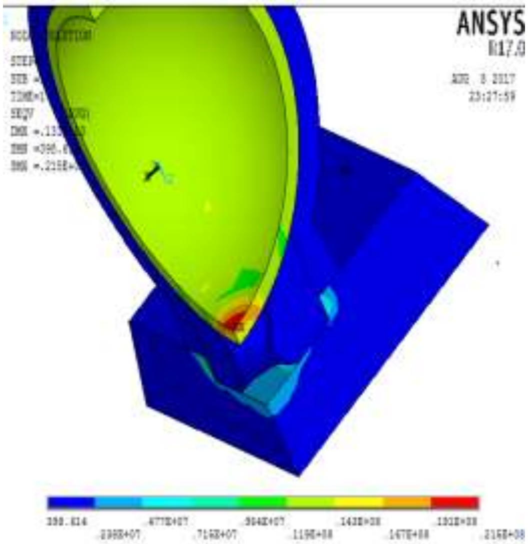


Figure 1.28: 7 mm Neoprene rubber insulation

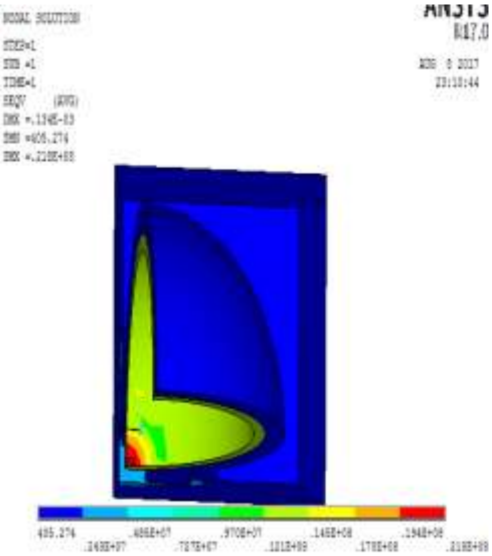


Figure1.29: 7 mm Natural rubber insulation

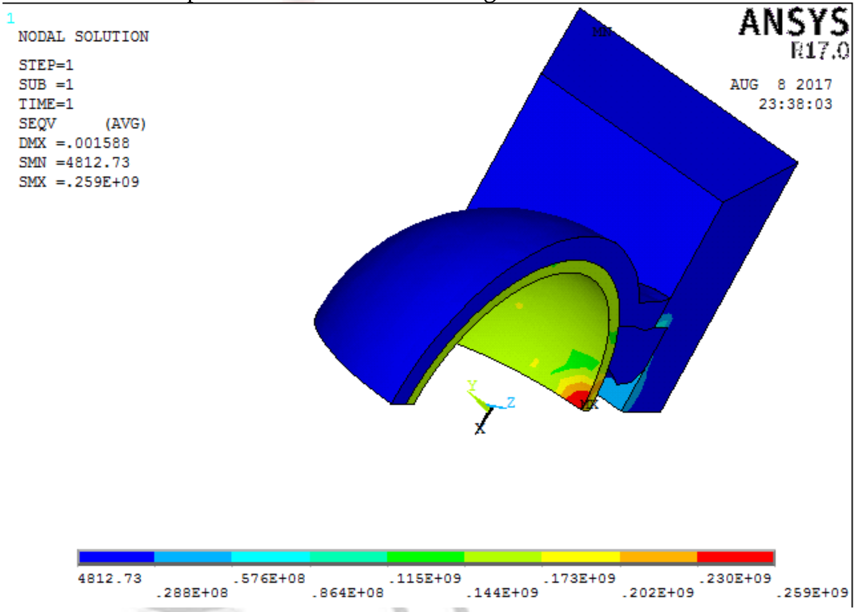


Figure 1.30: 7 mm Polyurethane insulation

7mm thick layer of Neoprene, Natural rubber and Polyurethane insulation is provided to transducer for reducing stresses and the result is shown in 1.25, 1.29 and 1.30.

At 7 mm thickness of both Neoprene and Natural rubber the stresses are reduced below the proof stress.

8.1.7 9 mm Polymer layer Insulation

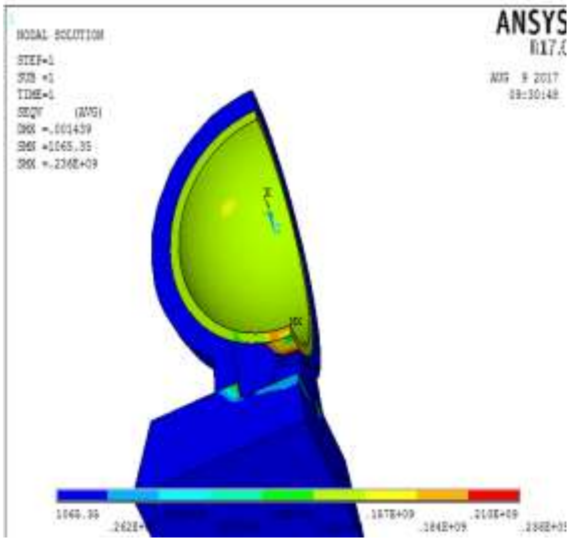


Figure 1.31: 8 mm Polyurethane insulation

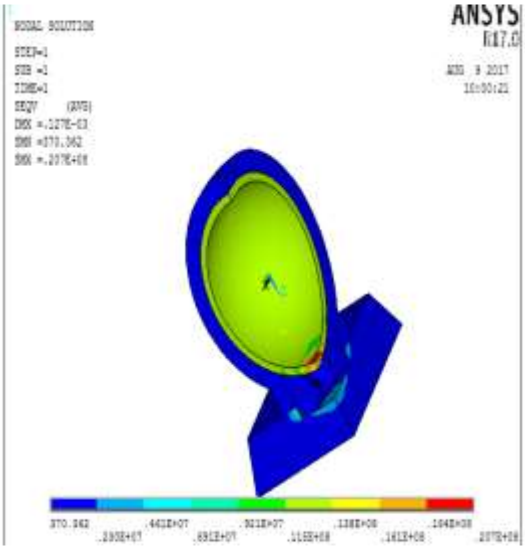


Figure 1.32: 9 mm Polyurethane insulation

By further proceeding to 8mm and 9mm thickness of Polyurethane stress is reduced below the proof stress at 9mm thickness and the result is shown in figures 1.31, 1.32.

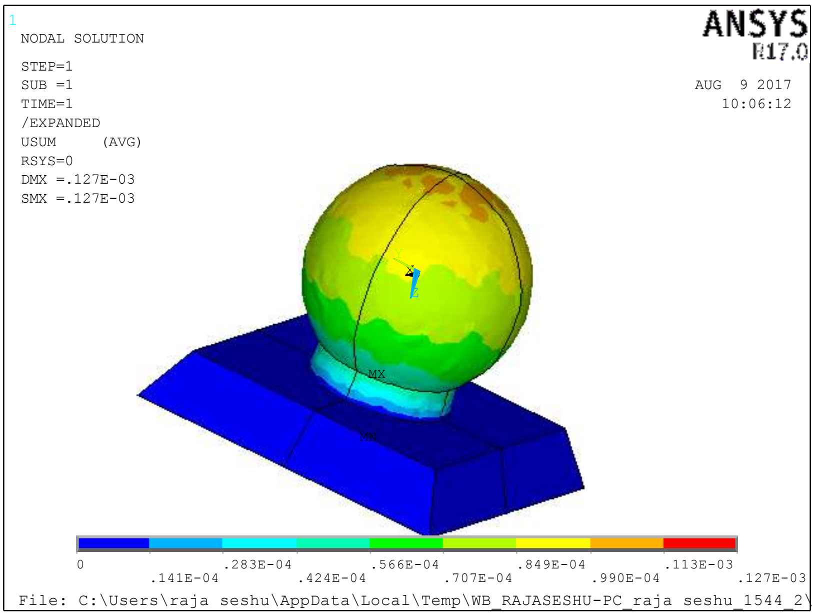


Figure 1.33: Deformation of Acoustic transducer at 6mm thickness.

Polymer Material	Maximum stress on the acoustic transducer at different thickness (MPa)						
	2mm	3mm	5mm	6mm	7mm	8mm	9mm
Nitrile rubber	33.5	27.9	24.6	**20.9**			
Neoprene rubber	34.4	28.8	26	24.8	**21.5**		
Natural rubber	34.8	29.1	26.9	25	**21.8**		
Polyurethane	35.3	33.6	29.9	28.1	21.9	23.6	**20.7**

Table 1.34: Stresses of Acoustic transducer at various thicknesses

The allowable stress of the ceramic transducer is 22.4 MPa. The transducer is fails at 2.6MPa pressure at 248 meters depth. Maximum stresses on ceramic transducer material are shown using bar chart.

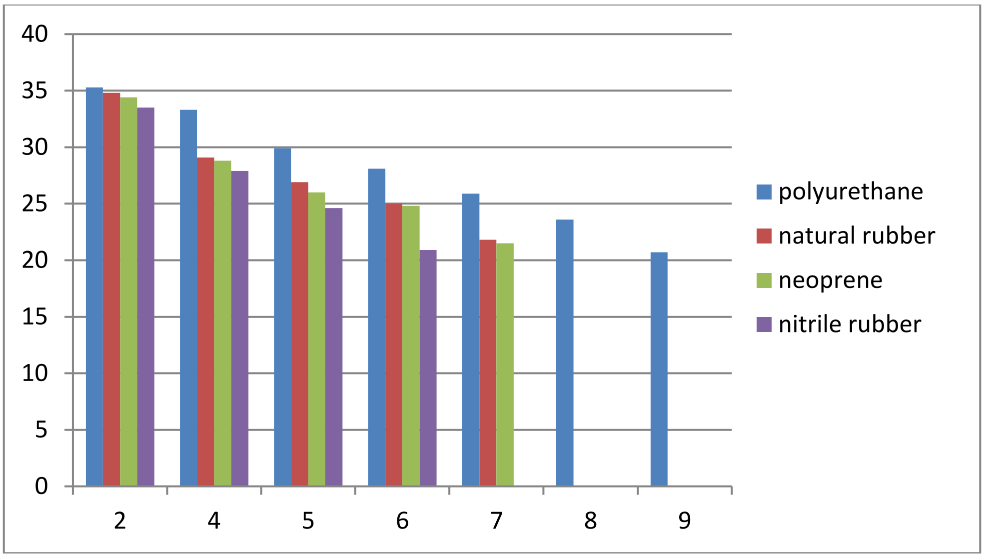


Figure 1.35: Maximum stresses on transducer for various thickness.

We have got stress below the proof stress at 6mm thickness for Nitrile rubber, 21.5 MPa for Neoprene rubber at 7 mm thickness, 21.9MPa for Natural rubber and 20.7MPa for Polyurethane at 9mm thickness

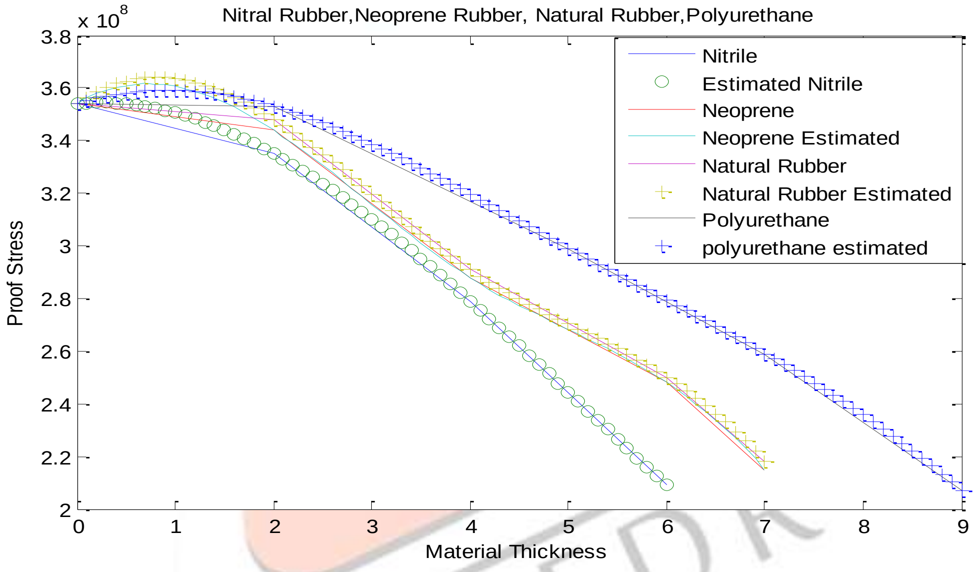


Figure1.36: Mate lab graph for different thicknesses

By using mat lab program we have check maximum stresses on acoustic transducers for various polymers at different thicknesses.

Conclusion:

- It can be observed that maximum stress of the Acoustic transducer is 35.4 MPa at 400 meters depth and proof stress is 22.4 MPa so the maximum stress below the proof stress is obtained at 6mm, 7mm and 9mm thickness of Nitrile rubber, Neoprene, Natural rubber and Polyurethane respectively.
- Performance of the transducer varies with thickness of the insulation. If thickness increases impedance increases and output accuracy will reduce so we have to reduce the width of insulation layer which can capable of minimizing the stresses. By acoustic test the allowable thickness for rubber materials is 7-8 mm thickness and for Polyurethane is 9-10 mm.
- It can be concluded that Nitrile rubber at 6mm thickness insulation of transducer is best to withstand high pressures and can sustain up to 400 meters depth.

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