Title

Effect of Biofouling on Acoustic Signals

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Synopsis

Marine biofouling has been largely believed to be transparent to acoustic signals. This paper however demonstrates that marine biofouling affects acoustic transmissibility and reflectivity of three commonly used materials. The composition of fouling organisms on the panels is recorded and an attempt is made to explain the measured acoustic characteristics by comparing the percentage cover of different functional groups of organisms.

Author's biographies

Parijat Deshpande has been working with the Acoustic Research Lab. at the National University of Singapore as a Research Engineer since 1997. He has a bachelor's degree in mechanical engineering from Govt. College of Engineering, India and a graduate degree in applied acoustics from Chalmers University of Technology, Sweden.
He primarily works on applied underwater acoustic research and designing underwater equipment for marine experiments.

Pallayil Venugopalan

Venugopalan Pallayil holds a post graduate degree in physics and a Ph.D in Microwave Electronics both from Cochin University of Science and Technology, India. Currently he is a Deputy Head (Resources) at the Acoustic Research Laboratory. He has been working in the field of underwater acoustics for nearly 18 yrs

Serena L-M Teo has been working on the ecology of marine biofouling communities in Singapore waters since 1992. She received her PhD in marine biology from University of Wales (Swansea) in 1992.

Introduction:

Biofouling or biological fouling is the undesirable accumulation of microorganisms, plants, algae, and animals on submerged structures. Biofouling has been studied by marine biologists and engineers alike, though generally from very different perspectives and for very different reasons. Engineers have been studying biofouling to develop suitable methods to reduce their detrimental effect on ship hulls, sea water carrying pipes, underwater sensors etc. and marine biologists to better understand these organisms and their ecosystem at large. In this paper, combined efforts from engineers and marine biologists towards determining the effect of marine biofouling on acoustic signals are presented.

To the best of our knowledge no work has been done to quantify the effect of biofouling on acoustic signals although it is acknowledged that severe fouling may obstruct transmission of acoustic signals[i]. There has been some work done on studying the biofouling on optic sensors as well as other marine sensors [ii iii]. In the food industry, acoustic methods have been used to detect fouling in pipes [iv] but there is little published information on the effect of natural marine fouling on acoustic signals. This knowledge is important as the presence of fouling on remote underwater acoustic devices may alter the signals being transmitted and received, resulting in distorted data.

Commonly used materials for underwater acoustic transducer windows such as Perspex, Neoprene and Aluminium, were selected and their change in acoustic properties due to marine bio-fouling was recorded. The transmission coefficients *(ratio of transmitted acoustic energy to total incident energy)* and reflection coefficients *(ratio of reflected acoustic energy to total incident energy)* were determined at various frequencies of interest ranging from 10 – 100 kHz over different fouling periods e.g. 2 weeks, 1 month, 3 months, 6 months, etc., then analyzed for the effect of bio-fouling on acoustic signals. These results were compared against the percentage cover scores of the fouling organisms present and a relationship between the level and nature of fouling with the variation in acoustic signals was estimated.

Deployment at Sea:

Three panels of each of the materials neoprene, perspex and aluminium were deployed at sea on a floating platform located at the RSYC Marina on the southern coast of Singapore (1° 17' 40"N, 103° 45' 37.6"E). Each of these panels 0.5m x 0.5m x 0.003m were mounted in PVC frames and suspended 0.5m below the water surface (Fig 1). A complete set of 9 panels were returned to the ARL test tank at regular time intervals for acoustic testing and scoring of fouling. The test tank at ARL is a $2x2x2m^3$ fresh water tank approx. 10min away from the deployment site. Since marine organisms are known to be averse to fresh water, transit time was maintained as less as possible. The test tank immersion time was kept no longer than ½ minute per panel. Panels were then returned to their location at sea within 60 minutes after testing.

Fig 1: Deployment at sea

Experimental Set-up:

The experimental setup for measurement of acoustic transmission and reflection coefficients of the panels consisted of two parabolic dishes approx. 0.45m in diameter with transducers ITC-1042 fitted at their foci. A parabolic dish was employed at the transmission side to generate a close approximation of a plane wave which was then transmitted through the test panels (0.5m x 0.5m) and re-focused at the receiving end using the second parabolic dish. The experiment was setup at the ARL 2 x 2 x 2 m^3 fresh water test tank and the parabolic dishes were placed 1.6m apart. The panel to be tested was mounted approx. midway between the dishes as depicted in Fig 2.

Neoprene used in the experiment was taken from a 3mm thick neoprene sheet compliant with ASTM D2000 5BC 615 Al4 B14 E034. Perspex™ used was taken from commonly used 3mm thick transparent acrylic sheet. Aluminium too was taken general purpose construction, 3mm thick sheets.

Fig 2: Parabolic dishes with a bare Neoprene panel mounted at the ARL tank facility

Instrumentation Schematic:

Fig 3: Instrumentation schematic

The transmission stage consisted of signal generation instrumentation using a PC based Matlab® program followed by digital to analog conversion using a National Instruments Data Acquisition Card and via the ITC 1042 transmission transducer # II mounted in a parabolic dish as shown in Fig3.

The receiving stage consisted of the receiving ITC 1042 transducer # I via analog to digital converter (NI-DAQ). The transducer # II acted as transmitter as well as a receiver for reflected signals. This was achieved without the need for a Tx/ Rx switch due to the fact that the parabolic dishes offered approx. 30dB gain over the selected frequency range and the entire time series recorded was within the dynamic range of the data acquisition system.

Acoustic Signal Processing:

A swept frequency signal whose frequency varied from 10 - 100 kHz in 1ms was transmitted and repeated 100-times for each panel. The sweep duration was chosen to ensure enough cycles at the lowest frequency. The time interval between 2 adjacent pulses was adjusted so as not to interfere with the reflected signal. The frequencies were so selected as to represent typical communication / SONAR frequencies. The pulse duration of 1ms corresponded to 1.5m in order to minimize the interference due to multi-path reflections in the tank.

The signal was corrected for the transfer function of the transducer ITC-1042 by implementing a digital correction filter and the corrected incident signal is shown in Fig 4.

This signal was then transmitted through each of the panels by transducer #2, repeated 100 times and received by the transducer # 1 mounted in the opposite parabola. 100 repetitions were taken so as to gain averaging advantage, especially required for a short signal (1ms). The sent signal was then used to match filter the received time series and extract the individual returns.

Each of these individual transmitted returns were extracted from the time series and plotted so as to overlap each other. These signals were then averaged and their power spectrum density was plotted.

Fig 4: Corrected input signal, through transmission, reflection (single sweep)

The transmission coefficient was computed by taking the ratio of the transmitted signal energy to the incident signal energy while the reflected coefficient was computed by taking the ratio of reflected signal energy to the incident signal energy. The power spectrum levels and transmission and reflection coefficients for each of the panels were plotted over frequency at various intervals beginning from 1 week to 14 weeks and analyzed to find a pattern in terms of the level and nature of fouling. The transmitted energy gradually dropped over time and the reflected / scattered energy was found to increase as anticipated. Since, the scattered energy was reflected in multiple directions due to the nature of the fouling surface, some of the scattered energy was lost.

During the initial stages the sum of reflected and transmitted energies was found to be in close approximation to the sent energy.

The transmission and reflection coefficients of bare panels was calculated and plotted as depicted in Fig 5. These results were then compared with the results from fouled panels to determine the effect of biofouling.

Fig 5: Transmission and reflection coefficients of Neoprene, Aluminium and Perspex panels

From Fig 5 it was observed that,

- The marginally higher value of the transmission coefficients (above 0dB) observed at certain places is due to experimental error.
- Neoprene demonstrated the best transmission characteristics while Aluminium the worst
- Aluminium provided some reflection due to its inherent metal composition at higher frequencies
- Perspex demonstrated slightly reduced transmission coefficients and higher reflection coefficients as compared to Neoprene

A set of 3 panels for each chosen material was analyzed to reduce the detrimental effects of singular results. Hence, a total of 9 panels were therefore deployed at the RSYC and tested at regular intervals. These panels were found to be completely covered by marine organisms by the 4th week as shown in Fig6.

Fig 6: Photos of Neoprene, Aluminium and Perspex panels after 4 weeks

Assessment of fouling cover on the panels:
The percentage cover of fouling on each panel was determined using point transect method. 100 random points were taken in 0.4m x 0.4m area in the centre of each panel. The fouling organism at each of the points was recorded, and the percentage cover estimated. Organisms were classified following the fouling classification system in Evaluating Biofouling Resistance and Physical Performance of Marine Coating Systems[[v]]. Hence, "tubeworms" consist of calcerous polychaetes from the families Serpulidae and Spirorbidae. "Barnacles" at the test site consist primarily of the acorn barnacle, *Balanus reticulatus* and *Balanus amphitrite*. Incipient fouling consists of immature stages of fouling, slime and silt. The variation amongst panels of the same material is represented in the bar graphs by the "I". The panels demonstrated different levels of fouling at the front and back of the panels largely due to their orientation with respect to the sun.

Fig 7: Average scoring results for Neoprene, Aluminium and Perspex panels at 4 weeks

CASE – I
Comparison of Transmission and Reflection Coefficients amongst panels at 4 weeks

Fig 8: Transmission and Reflection Coefficients of panels after 4 weeks

Transmission and reflection coefficients were calculated for individual panels and compared

As seen from Fig 8, Perspex demonstrates approx. 5dB improved transmission coefficient as compared to Aluminium and Neoprene i.e. the transmission coefficient of Perspex is not affected as much as Aluminium and Neoprene over the same period. It is noted that barnacle growth on the Perspex panels is at 15% i.e. less than that of the other two (Fig7).

The 5 dB improved Transmission Coefficients in Perspex may be attributed to lower barnacle growth on Perspex as compared to Aluminium and Neoprene.

CASE – II
Comparison of Transmission and Reflection Coefficients of Neoprene panels at 4 and 8 weeks

Fig 9: 4 & 8 weeks fouling plots for Neoprene Panels

It was observed that the average transmission coefficients dropped over 10dB over frequency for all the panels, in particular for Neoprene. It was observed that hard fouling cover, in particular barnacles, had increased significantly over the 4- 8 weeks period.

Thus, this 10 dB drop in Transmission Coefficients in all the panels may be attributed to higher barnacle growth on all the panels, particularly in Neoprene.

Fig 10: Scoring plots of Neoprene, Aluminium and Perspex at 8 weeks

CASE – III

Fig 11: Average Transmission and Reflection Coefficients of Aluminium at 4 and 8 weeks

The average transmission coefficients dropped by approx. 10dB mainly at the lower frequencies while the reflection coefficients for Aluminium increased by about 10dB over the entire frequency range with a peak at 30 kHz. It was observed that the Aluminum panels had more tubeworm cover (Fig10) than for Perspex and Neoprene at 8 weeks. Unlike barnacles, tubeworms form a dense layer on the surface and may contribute towards reflection. Barnacles, although they also have a calcerous shell, they are expected to cause greater scattering of the acoustic signals as they form an uneven jagged surface.

Discussion:

The complete data were plotted from 4 – 8 weeks and the variation amongst panels of same materials was analyzed and plotted in terms of spectral curves as well as the actual fouling cover in order to deduce a possible relationship between fouling organisms and their effect on acoustic signals. This data, though not conclusive towards deriving a relationship, definitely offers an estimate in the change in acoustic signals based on the nature of fouling.

This attempt is the first of its kind to deduce the effect of marine biofouling on acoustic signals on materials immersed in the open sea environment. Unlike in laboratory studies, the natural fouling community is extremely diverse and heterogeneous in composition. It was demonstrated that, depending on the composition of hard and soft fouling organisms present, acoustic transmission and reflection coefficients of different materials were affected differently. More detailed studies are being pursued to understand this relationship.

Conclusions:

- As expected from its widespread use in underwater acoustic devices, neoprene was found to be a near perfect acoustically transparent material and allowed almost all the energy to be transmitted through a blank panel. However, it also was the very first to be fouled and transmission coefficients dropped by 10dB over the 4-8 week period due to barnacle growth.

- Aluminium demonstrated reflective characteristics at the higher frequencies of 50 – 100kHz for bare panels. There was a 10dB increase in reflection coefficient possibly attributed to the increase in tubeworms on the Aluminium panels at 8weeks.

- Perspex demonstrated the least fouling growth during the first week. Tubeworms settled on the Perspex panels in the first few weeks but were subsequently overgrown with barnacles and mollusks by 8 weeks. The modest fouling growth on Perspex translated to approx. 10dB drop in the transmission coefficient over 8 weeks and less than 5dB increase in the reflection coefficient possibly attributed to growth of barnacles in the later period.

Future Scope:

- To conduct more detailed experiments to quantify the change in acoustic properties of materials based on transmission and reflection coefficients in relation to fouling composition.
- Examine the relationships between the different fouling organisms contributing to the fouling and the resulting transmission and reflection coefficients over frequency using statistical methods such as ANOVA to map their effects at various frequencies.
- Demonstrate the growth of fouling over time over different materials with and without anti-fouling paints e.g. InterSleek.
- Repeat the experiment at sea with in-situ apparatus or salt water test tank facility
- Use other acoustic window materials such as polyurethane.

Acknowledgements:

The authors would like to acknowledge sincere efforts from both Hu Xiao Ping and Md. Razali towards the tedious task calculating meticulous fouling scores of each individual panel and Dr. P. Seekings for his help in Matlab® programming.

References:

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[ii] Cowling, M. J , Hodgkiess . T, et al Biofouling of Oceanographic Sensors – Is there a solution? , University of Glasgow

[iii] Lemoine, L et al Experimental Assessment of effect of marine fouling on sensors IFREMER Report DITI/Go/MM-93-06, 1993

[iv] Lohr, K.R., Rose, J.L., 2002, "Ultrasonic Guided Wave and Acoustic Impact Methods for Pipe Fouling Detection", Journal of Food Engineering, 56, pp. 315-324.

[v] ASTM Standard D6990-05 Evaluating Biofouling Resistance and Physical Performance of Marine Coating Systems

Figs:

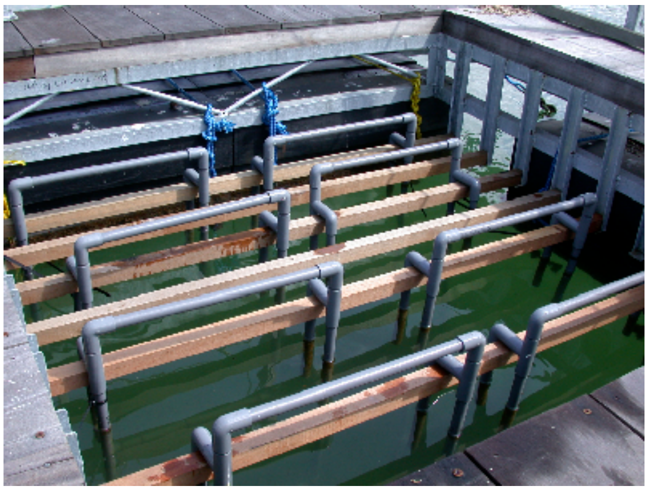


Fig 1: Deployment at Sea from RSYC Marina

Fig 2: Parabolic dishes with a bare Neoprene panel mounted at the ARL tank facility

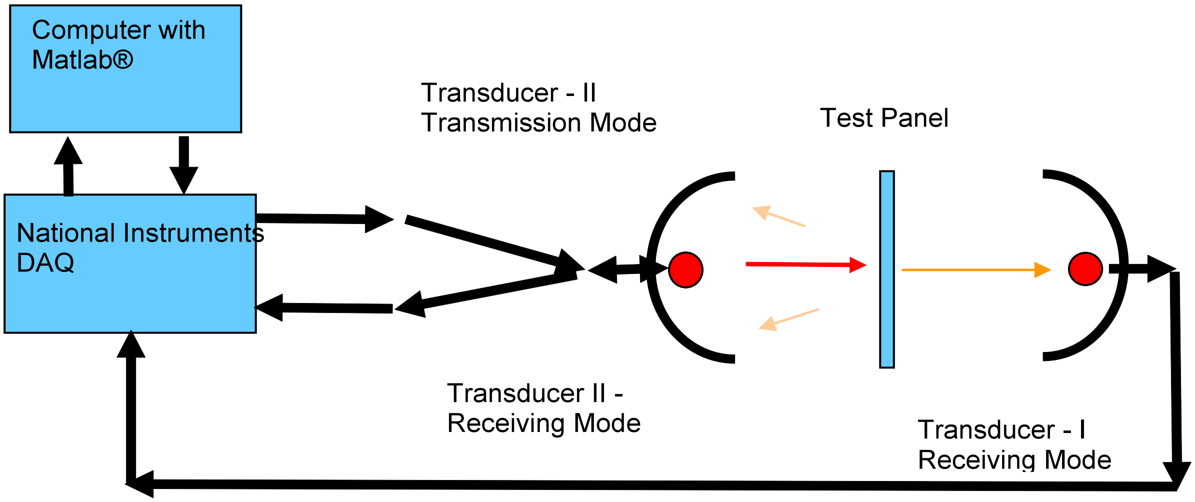
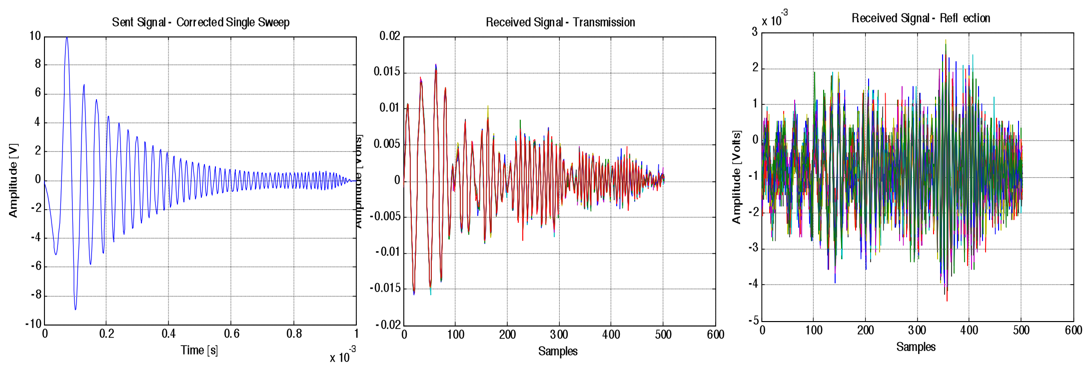
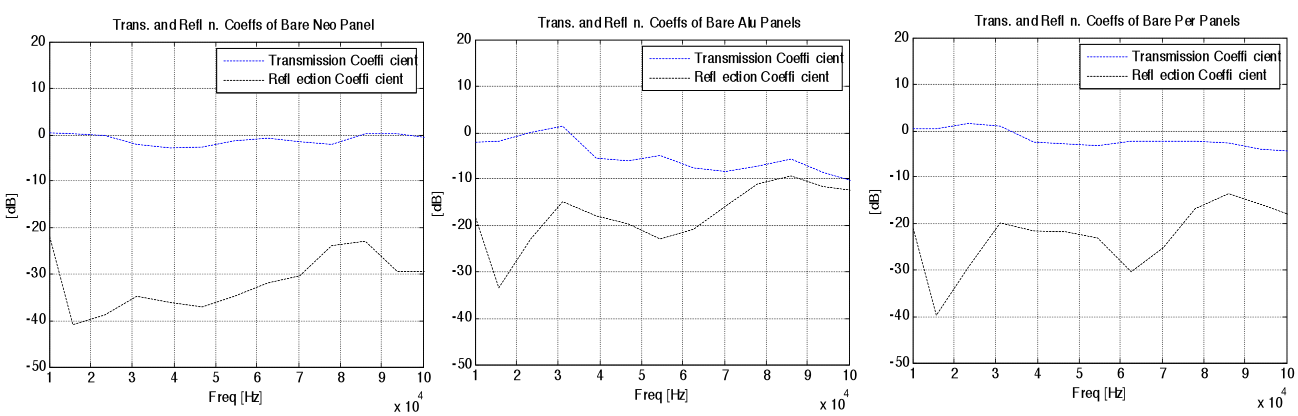


Fig3: Instrumentation Schematic



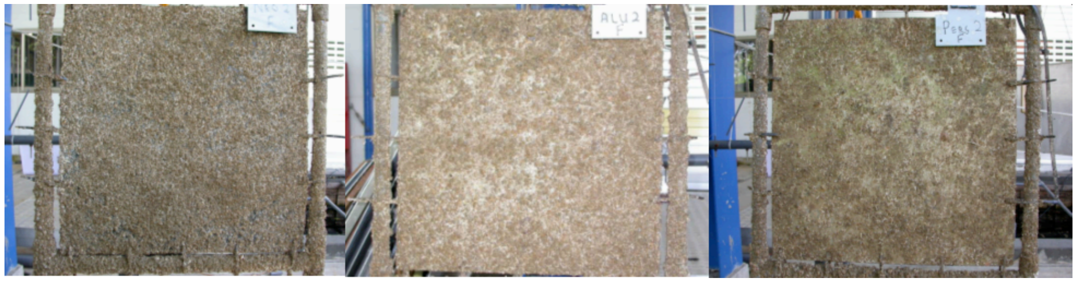
Sent Signal Through Transmitted Signal Reflected Signal

Fig 4: Corrected Input Signal, Through Transmission, Reflection (Single Sweep)



Bare Neoprene Panel Bare Aluminium Panel Bare Perspex Panel

Fig 5: Transmission and Reflection Coefficients of bare Neoprene, Aluminium and Perspex panels



Neoprene Panel Aluminium Panel Perspex Panel

Fig 6: Photos of Neoprene, Aluminium and Perspex panels after 4 weeks

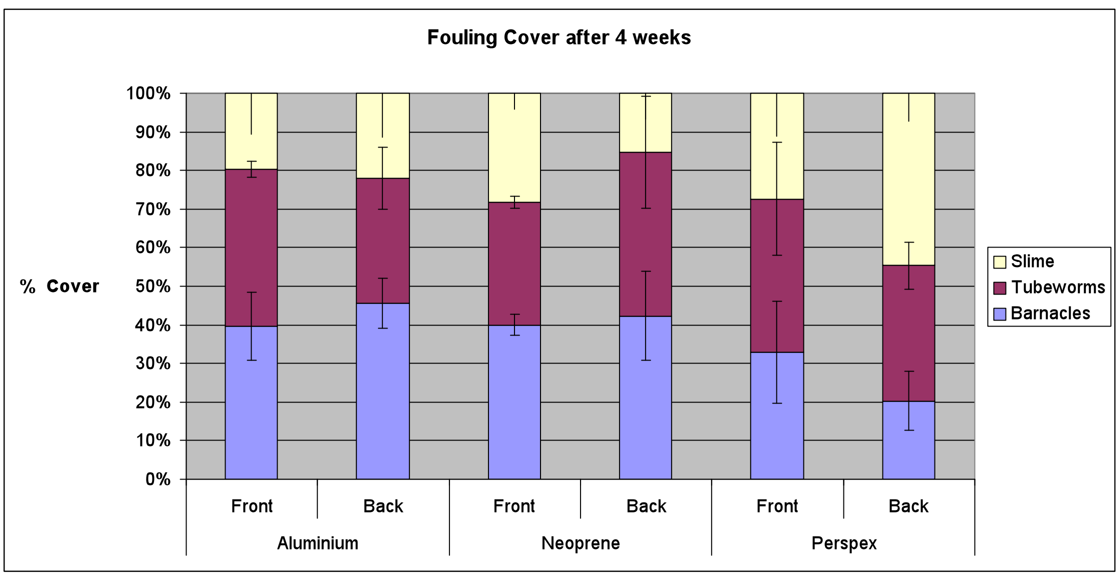
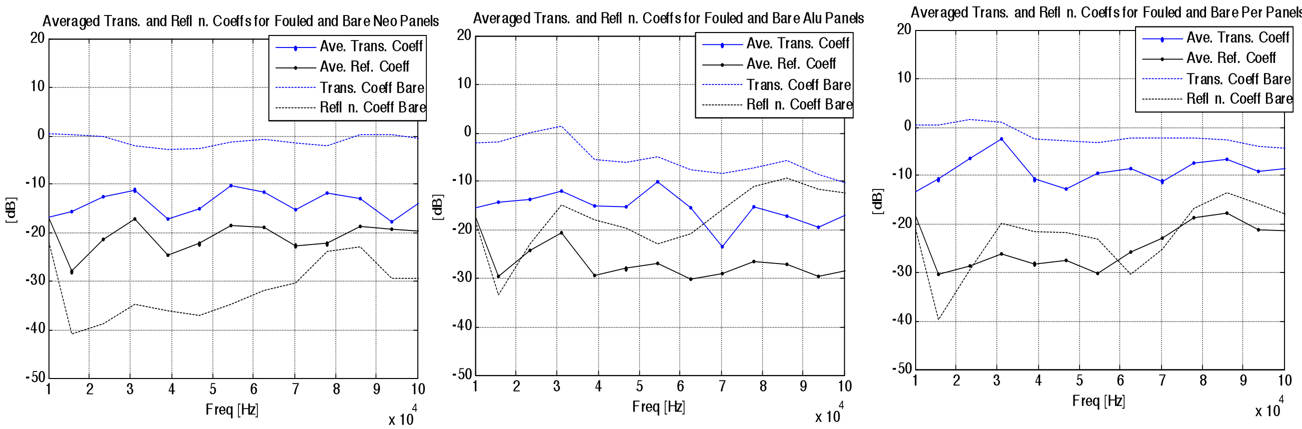
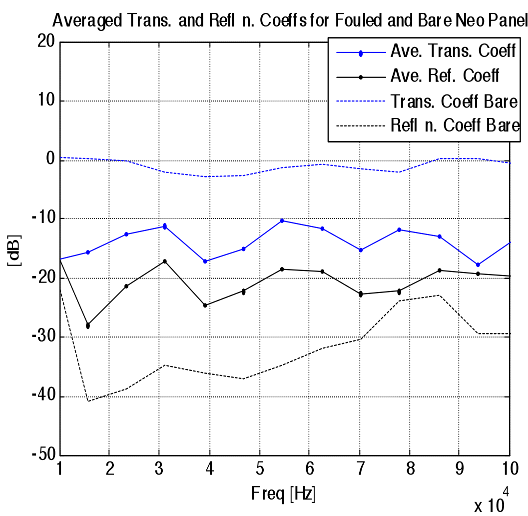


Fig 7: Average Scoring results for Neoprene, Aluminium and Perspex Panels at 4 weeks



Neoprene Panel Aluminium Panel Perspex Panel

Fig 8: Transmission and Reflection Coefficients of panels after 4 weeks



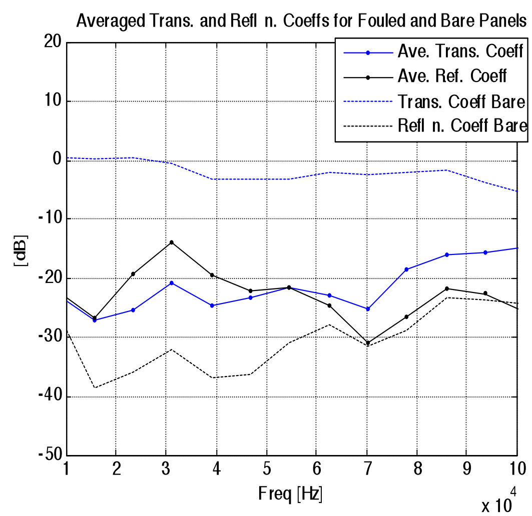


Fig 9: Average Transmission and Reflection Coefficients of Neoprene at 4 weeks

Average Transmission and Reflection Coefficients of Neoprene at 8 weeks

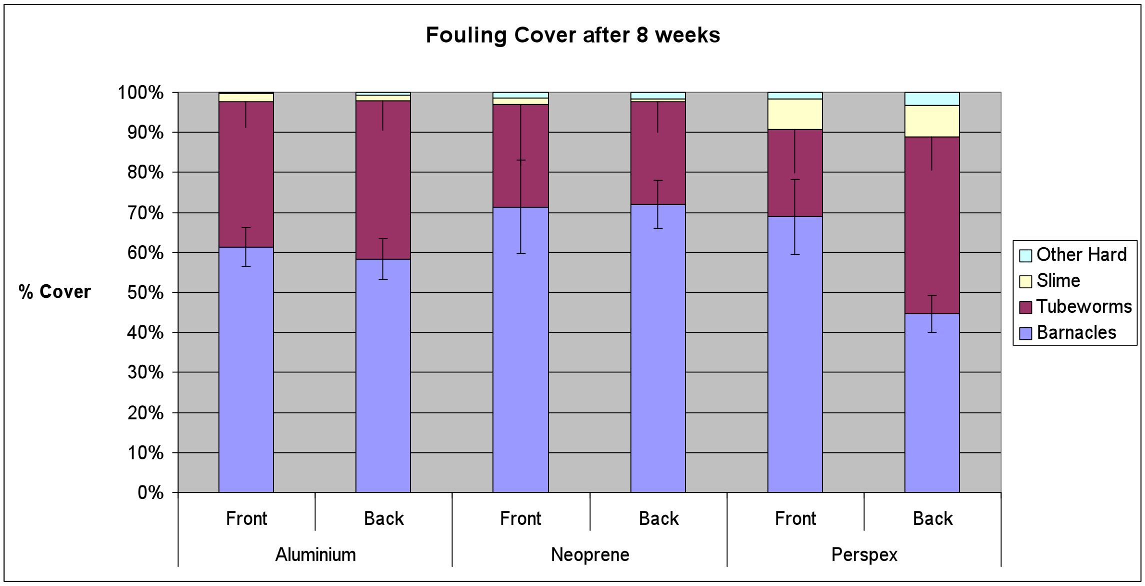


Fig 10: Scoring plots of Neoprene, Aluminium and Perspex at 8 weeks

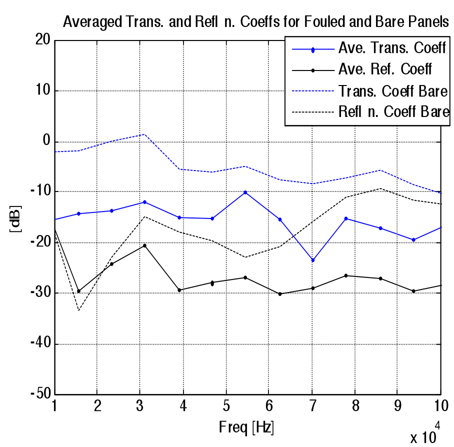
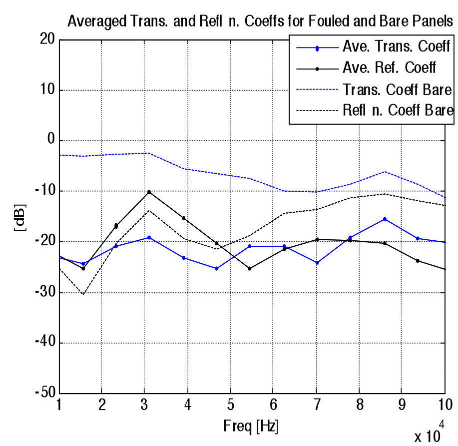


Fig 11: Average Transmission and Reflection Coefficients of Aluminium at 4 weeks



Average Transmission and Reflection Coefficients of Aluminium at 8 weeks