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THERMO-ACOUSTIC PROPERTIES OF ELASTOMERIC PIPELINE INSULATION

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ABSTRACT

A majority of current types of pipeline insulation products in marine and offshore sector relate to glassfibre, mineral and rockwool products which are protected by a heavy layer of lead or stainless steel. These systems have a number of disadvantages related to its weight and corrosive properties. In addition, the re-radiation effect, acoustic energy transference into pipe supports and poor compliance resulting from the metal cladding tend to reduce the performance of these insulation systems. An alternative system is to use a multi-layer structure which is composed of a number of poro-elastic layers with properties being carefully selected to ensure a good acoustic insulation and vibration damping performance. This work studies the vibro-acoustic performance of a new type of elastomeric insulation which is a polymeric heavy barrier layer applied to a stack of open, semi-close and close cell foams bonded in a sandwich structure which is almost 50% of the weight of a conventional fibrous insulation system. This sandwich structure can be modelled as a multiple degree of freedom system and tuned to the designed acoustic performance. Independent tests show that these new insulation systems meet the transmission loss requirements outlined in the new ISO 15665 standard for acoustic insulation specification.

1 INTRODUCTION

Acoustic cladding has been used in the marine and offshore industry for several decades. In the early years, asbestos with metal covering provided the typical insulation solution. An industry-wide ban on the use of asbestos means that mineral wool and glass-fibre products are now typically used instead. Although these products have reasonable thermo-acoustic properties, as well as a high level of fire protection, they can cause the contactor several problems. Firstly, these materials have an open-cell structure, which under the harsh conditions of the marine and offshore environment can readily take up large quantities of water that enters in through the gaps between joints and seals of the outer metal cladding. Not only can this dramatically reduce the acoustic and thermal performance of the insulation, under-insulation and galvanic corrosion can occur as a result of the water retention in the porous structure. In order to prevent further corrosion, reduce thermal losses and ensure that health and safety requirements are adhered to, the insulation may typically require replacing after only a few years of service. The process of re-insulation is both time consuming and labour intensive and is reluctantly conducted at great expensive.

Closed-cell elastomeric materials are often used as a cleaner alternative to mineral wool based systems for thermal protection in commercial and domestic pipe-work applications. As well as offering improved protection against corrosion, continuing developments in elastomeric chemistry have enabled these products to meet stricter fire performance requirements. In recent years contractors have begun to use these products for thermal insulation work in the marine and offshore environment.

Currently these products possess only limited noise reduction properties, but in an age where 'multi-functionality' is an ever-increasing requirement for many applications, the demand to find an insulation system that meets both thermal and acoustic requirements, offers improved durability and protects the pipe work against the elements, is clear.

This paper describes work conduced on new types of elastomeric insulation systems which have been designed specifically for noise control applications and to protect against under insulation corrosion (UIC). These insulation systems have been initially tested in the laboratory using a large loudspeaker rig and then in accordance with the new ISO 15665 acoustic standard for testing pipeline insulation performance. These systems also meet the thermal requirements demanded by the industry.

2 TRADITIONAL INSULATION SYSTEMS

Traditional insulation systems for marine and offshore pipeline applications involve the application of an open-cell fibrous material directly to the pipe, which is protected by a water vapour barrier and metal cladding to isolate the porous structure and the pipe from the external elements. A typical application of pipeline insulation is shown in Figure 1 together with the elements to which this system is typically exposed.

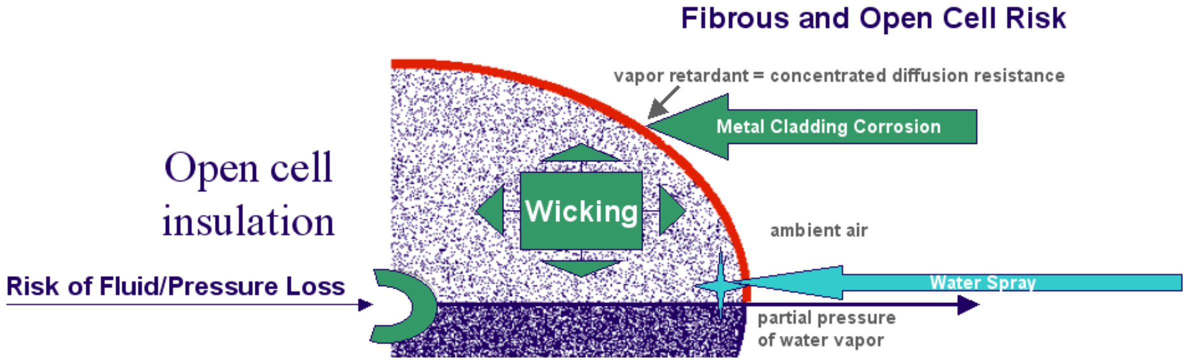

Figure 1: Annotated diagram showing fluid ingress effects within a traditional fibrous layer and for which the outer metal jacketing has been damaged.

The major disadvantage of fibrous insulation systems is that the porous structure of these materials is constructed from a very high proportion of open capillary pores, i.e. >90%. These pores are open to fluid transport in and out of the material. As a result, the performance of fibrous insulation systems depends heavily on the integrity of the metal cladding, which serves as the added mass and moisture vapour barrier. In this case, poor installation or damage to the cladding is likely to allow the ingress of water, dust and fumes into the fibrous lining.

The wicking, or capillary effect, of the fibrous liner will allow moisture to be transferred to the surface of the pipe and retained over a long period of time. The moisture picked up by the insulation material can easily react with oxygen present in the material pores so that under insulation corrosion (UIC) can rapidly occur on the surface of the pipe. This process is exacerbated by the presence of a foreign metal on the outer skin of the fibrous insulation layer and the presence of moisture throughout the layer contributing to galvanic corrosion of both the metal pipe and the cladding. These effects are illustrated in Figure 2, which shows the state of the mineral fibre layer and the outer surface of the metal pipe after a few years of exploitation of the fibrous acoustic insulation system in a humid atmosphere.

Figure 2: Examples of UIC effects on metal pipe work insulated with traditional mineral wool/metal cladding systems after only a few years of service.

The primary concern about the performance of the acoustic insulation system is that in extreme cases the level of corrosion can be so high that there is a serious risk of pipelines failing which can ultimately cause a dramatic loss of pressure through the pipe wall. Such hazards pose a serious H&S issue and moreover, one which is very difficult to predict and locate. As a result, there are anecdotal evidence that offshore companies refuse to insulate their pipelines because of a serious risk of UIC which can lead to pipe perforation and escape of hazardous fluids or gases at considerable pressures. This can present greater health and safety issues than that which may be caused by the exposure to noise radiated by the uninsulated section of a high-pressure pipe.

In addition, there is evidence to suggest that moisture ingress into an open-cell layer can have a detrimental effect on both the acoustic and thermal performance of the system. From the thermal aspect, the presence of moisture will increase the thermal conductivity compared to the case of a dry fibrous layer. It is widely accepted that a 1% increase in moisture content will lead to a 6% increase in thermal conductivity. From the acoustic point of view, the material absorption performance has been observed to diminish with the increased amount of moisture residing in the material pores [1]. In addition, one can expect that the presence of moisture will affect the dynamic stiffness of the fibrous insulation system and therefore its vibration isolation performance. It should be noted that the above effects of moisture on the performance have never been studied systematically and cannot be accounted for by any of the existing acoustical and thermal insulation standard testing procedures.

3 ELASTOMERIC INSULATION

Close-cell elastomeric materials have long been recognised for their beneficial thermal insulation properties in comparison with more traditional fibrous materials. However, until recently, their acoustic insulation performance has not been fully explored. New studies by Armacell UK Ltd and the University of Bradford (UK) suggest that elastic, closed cell foams can be designed to achieve excellent vibro-acoustic insulation performance in stand-alone applications or in combination with other open-cell elastomeric products. In contrast to traditional layers of mineral wool and metal cladding, close-cell elastomeric systems can be manufactured in the form of highly flexible layers which is impregnable to moisture, dust and fumes. These layers can serve simultaneously as a thermal insulation system, an acoustic insulation system and water vapour barrier. This benefit is illustrated in Figure 3 below.

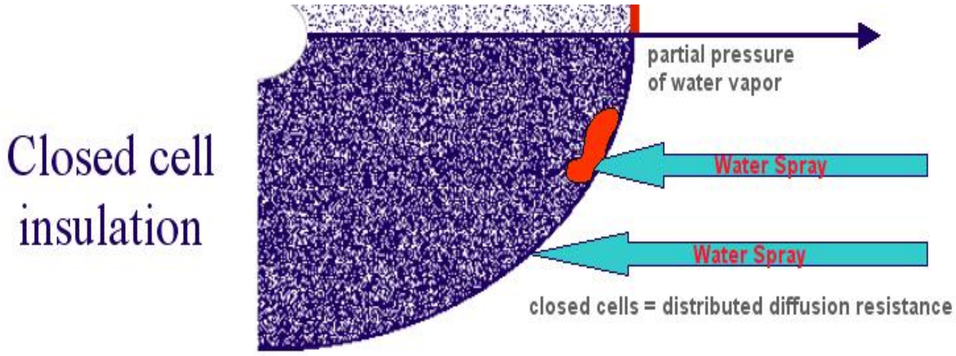

Figure 3: Annotated diagram showing integral and continuous protection from a layer of closed cell elastomeric insulation and for which the outer protective covering has been damaged.

Figure 3 shows that the closed cell structure of these materials insures that any damage to the insulation covering is localised and the integrity of the overall insulation system against moisture ingress and airborne sound is maintained. It is common to expect that very little moisture will be able to penetrate an elastomeric insulation system during the service term of a pipeline, irrespective of the pipeline temperature and relative humidity of the surrounding environment. As a result the insulated pipe surface is much less likely to corrode than in the case of traditional fibrous systems. This is demonstrated in Figure 4, which shows the condition of the insulated chilled pipe after over 20 years of service. In this way the pipeline service costs are reduced and its life expectancy is only determined by its internal conditions. The acoustic and thermal insulation performance of these systems is less prone to the effects of external moisture, pipe corrosion and the metal cladding degradation. The thermal insulation of close cell foams is superior to open cell products (e.g. rockwool or fibreglass) and it is typical to expect their thermal conductivity is 33 mW/mK or better which provides up to 10% energy saving over a 10-year period of exploitation.

4 ACOUSTIC INSULATION PERFORMANCE

Currently the acoustic performance of pipeline insulation system is tested in accordance with ISO 15665, ‘Acoustics – Acoustic Insulation for Pipes, Valves and Flanges’ [2]. This standard is the recent replacement for the previously used OCMA - NWG5 standard [3]. The new standard is designed to enable noise control engineers to specify the correct type and thickness of insulation in order to achieve a specific noise level reduction and presents a classification procedure for the assessment of the quality of pipeline insulation. Table 1 shows the insertion loss values required for a particular insulation system to comply with the 3 classification criteria at each of the octave band centre frequencies. Each of the three classifications is split into 3 sub classes to account for re-radiation effects for pipelines of different diameters.

Class	Range of nominal diameter D mm	Octave band centre frequency, Hz						
		125	250	500	1 000	2 000	4 000	8 000
		Minimum insertion loss, dB						
A1	$D < 300$	–4	–4	2	9	16	22	29
A2	$300 \leqslant D < 650$	–4	–4	2	9	16	22	29
A3	$650 \leqslant D < 1\,000$	–4	2	7	13	19	24	30
B1	$D < 300$	–9	–3	3	11	19	27	35
B2	$300 \leqslant D < 650$	–9	–3	6	15	24	33	42
B3	$650 \leqslant D < 1\,000$	–7	2	11	20	29	36	42
C1	$D < 300$	–5	–1	11	23	34	38	42
C2	$300 \leqslant D < 650$	–7	4	14	24	34	38	42
C3	$650 \leqslant D < 1\,000$	1	9	17	26	34	38	42

Table 1. Acoustic performance classification of the pipeline insulation and minimum insertion loss requirements [2].

Figure 4: Example of cold water pipeline which has been insulted with closed cell insulation (Armaflex) for more than 20 years.

In addition to the 3 ISO 15665 Classes, there is a further D classification which is currently used in by Shell as part of their DEP specification [4]. It is anticipated that this classification may be incorporated into the ISO15665 classification in the near future and so has been included in the scope of this work.

The ISO 15665 standard also presents typical octave band noise emission spectra for 4 common types of noise sources: centrifugal compressors, reciprocating compressors, centrifugal pumps and control valves. This data may be used by the noise control engineer to calculate the typical noise reduction achievable in application of a given sound insulation system if the spectrum of noise is not known. For a given octave band noise spectrum, L_i, and octave band insertion loss values IL_i, the resultant noise level is then calculated as the difference $L_{with,i} = L_{without,i} - IL_i$. The broadband resultant noise level is then predicted from logarithmic sum $L_B = 10\log_{10}\left(\sum_{i-1}^{N} 10^{\frac{L_{with,i}}{10}}\right)$. This level is then compared against the standard permissible personal exposure levels so that decision on the occupational noise risk to the personnel can be made. Therefore in this process the fundamental property for the acoustic performance of the pipeline insulation system is its octave band insertion loss and is measured in accordance with the standard testing procedure detailed in section 10.3 of the ISO 15665 [2].

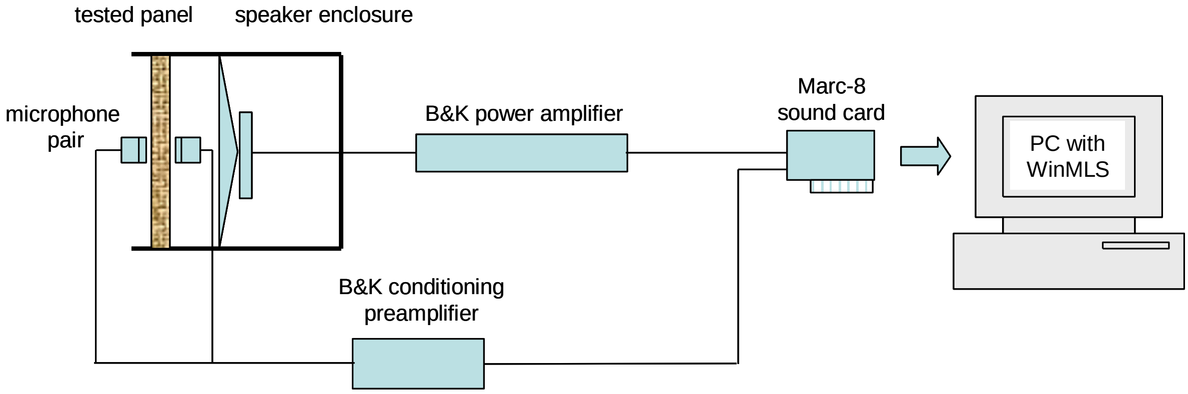

Figure 5. Schematic representation of the laboratory transmission test setup.

Initially a single layer of closed cell foam (Armaflex) has been tested using a laboratory setup developed at the University of Bradford. This test measures the airborne transmission loss using a 490mm loudspeaker rig shown in Figure 5. The rig is heavy and has a square aperture of 0.5m x 0.5m. The signal emitted by the 1000 Watt speaker is a 16-order MLS noise sampled by a matched microphone pair. The audio channels are calibrated and the sound pressure level difference between the two microphones is calculated in the frequency range of 100 – 10000 Hz. The external microphone is set at 20mm from the clamped material specimen and it is moved at a number of positions to obtain a representative level difference across the panel surface. The position of the internal microphone is fixed at 20mm from the centre of the internal surface of the panel. The transmission loss is measured in 1/3-octave bands which centre frequencies fall in the above frequency range. The transmission loss is then calculated as the difference between the calibrated sound pressure levels as detailed in ref. [2]. Although this is not a standard test, it still provides a good comparative estimate of the transmission loss performance of acoustic insulation and allows a large number of limited area samples to be rapidly evaluated for the transmission loss performance. Figure 6 presents an example of the transmission loss (sound pressure level difference) obtained for a single elastic plate and the plate loaded with a poro-elastic layer.

The results of the laboratory transmission loss experiments suggest that closed cell foams possess limited performance in the low frequency regime although reasonably good insertion loss values can be observed at higher frequencies. The insulation system can be significantly improved when metal cladding is used around the outside of the insulation in order to provide an additional barrier, but the lack of an acoustic dissipation mechanism limits its effectiveness.

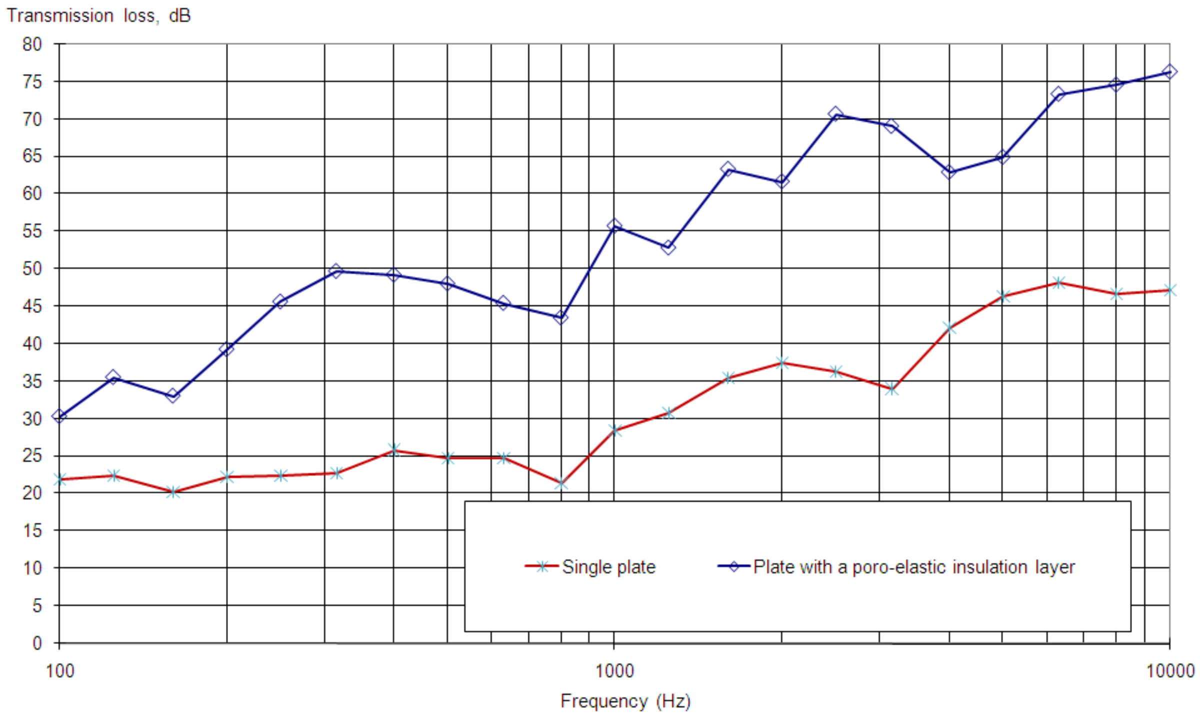

Figure 6. An example of laboratory transmission loss data obtained in the airborne transmission loss experiment.

In order to improve the performance of the elastomeric insulation it was clear that an acoustic absorption layer was required because closed-cell materials do not typically posses good acoustic absorption properties. The locked cell structure of these materials restricts air movement inside the cell structure limiting the visco-thermal absorption and resulting in the increased dynamic stiffness. For this reason a new open-cell material was introduced into the insulation system. Such a layer would enable the airborne component of the acoustic waves to be absorbed through a process of visco-thermal exchanges taking place inside the porous structure and extra visco-elastic damping provided by the frame of a heavier open cell layer. Figure 6 illustrates the typical effect of poro-elastic layer on the airborne transmission loss of a thin elastic plate.

Recent studies conducted at the University of Bradford showed that a new form of technology enabled closed-cell elastomeric materials to be re-engineered into high performance, open-cell, acoustic absorption materials [5-7]. These materials were designed to absorb a high level of sound within a limited space. Such technology was based around the concept of sustainable engineering in such a way as to alter the micro-structural properties of a granulated recycled waste in order to achieve a new product with improved sound absorption, desired dynamic stiffness, damping and specific density. In particular, the effect of the flow resistivity, porosity, tortuosity and pore size distribution on the acoustic absorption and transmission loss performance of many material formulations has been studied. The random incidence absorption coefficient (RIAC) data for a particular product, ArmaSound 240, shows that at 25mm thickness, the absorption values are greater than 0.8 above 500Hz. Absorption in this frequency regime would bring a significant improvement to the performance of an insulation system applied to pipe work. In addition, this material exhibits a relative high damping ratio of greater than 30% in the frequency range between 60 and 800 Hz. It is a relatively dense (240 kg/m^3) and behaves like a loading mass in combination with relatively light layers of close cell foam (50 kg/m^3). These considerations have been confirmed by the results of the laboratory experiments. A new insulation system has been designed in that a 25mm thick layer of ArmaSound replaced a proportion of the overall insulation system. It was sandwiched between impervious elastic layers protecting it from the moisture ingress. In order to improve the acoustics of the system further by exploiting the vibration insulation behaviour of multiple spring-mass vibration elements, a dense, thin, impervious rubber barrier, Arma-Chek R, was applied to the outer layer. In the case of the highest performance system, an additional internal layer, ArmaSound Barrier, was also applied in order to increase surface mass. The barrier layers' high density, flexibility, environmental resistance and water repellent properties served as a both a noise reduction mechanism and protective covering. The densities of each layer were as follows: Armaflex – 50kg/m^3; ArmaSound 240 – 240kg/m^3; ArmaSound Barrier – 2500kg/m^3 and Arma-Chek R – 1600kg/m^3. A combination of several poro-elastic layers ensures that the required acoustic performance is achieved with a relatively thin insulation system which is nearly 50% lighter than conventional systems composed of fibrous layer and metal cladding.

Four basic sandwich material configurations have been studied in the laboratory and selected for a standard ISO 15665 test. The material makeup of these systems is shown in Figure 7. In particular, System A shows a composite consisting of 2 layers of 25mm closed cell Armaflex and a impervious covering layer of 2mm Arma-Chek R. System B shows a composite consisting of 1 layer of 25mm Armaflex, 1 layer of 25mm open cell ArmaSound and 1 layer of 2mm Arma-Chek R. System C shows a composite consisting of 1 layer of 25mm Armaflex, 1 layer of 25mm ArmaSound, 1 layer of 2mm ArmaSound Barrier, 1 layer of 2mm ArmaSound Barrier, 1 layer of 3mm ArmaSound Barrier and 1 layer of 2mm layer Arma-Chek R. Finally, System D shows a composite consisting of 2 layers of 25mm Armaflex, 2 layers of 25mm ArmaSound, a 4mm layer of ArmaSound Barrier and a 2mm layer of Arma-Chek R.

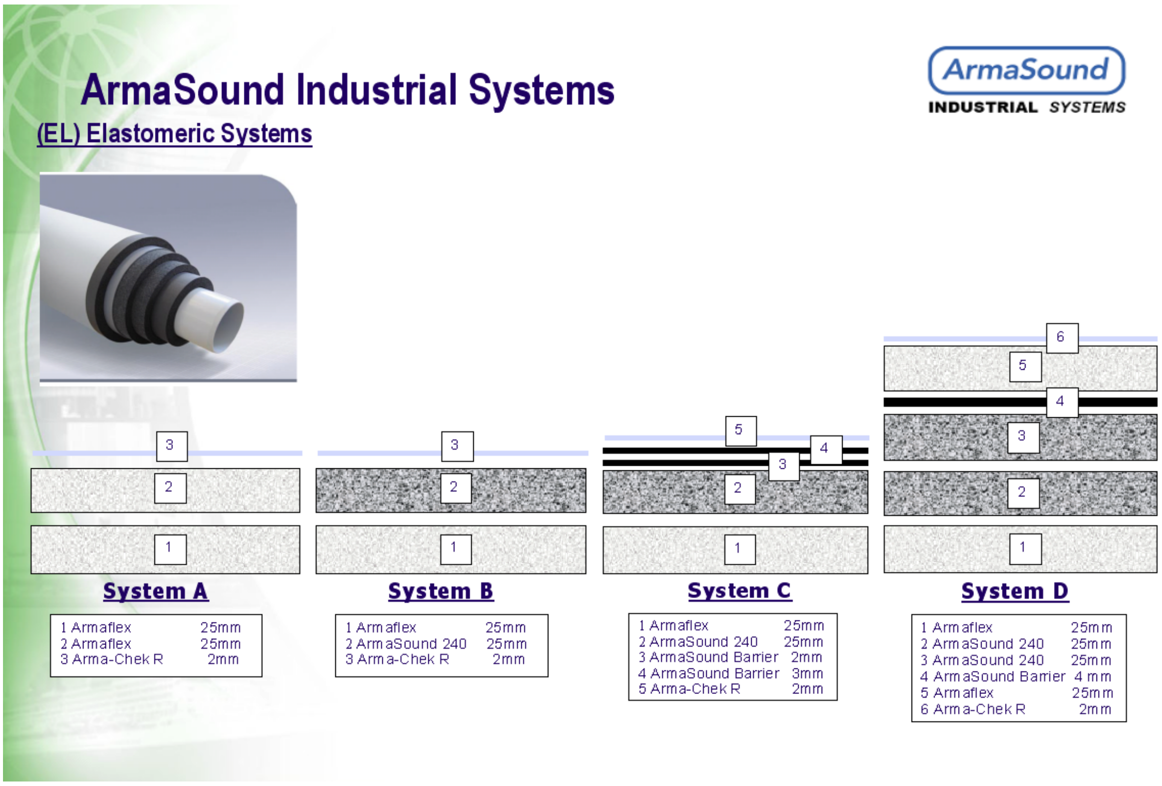

Figure 7: Diagram to show the sandwich construction for each of the 4 ArmaSound Industrial Systems acoustic insulations systems proposed (Inset showing System D configuration).

The measured octave band insertion losses for the proposed systems have been determined in accordance with ISO 15665 during testing at Peutz Consultancy in the Netherlands [8] between the periods of 2003 to 2007. The results are presented Figures 8. These figures also present the insertion losses required by the standard acoustic insulation classes [2] (see Table 1).

In order to make an assessment of the performance of the developed insulation systems, the predicted noise level reduction was determined for each of four source examples. Table 2 shows the broadband insertion loss results of the ArmaSound Industrial Systems and compares them against the equivalent class performance values. These values have been calculated and corrected for A-weighting in accordance with the procedure defined in the ISO 15665 standard. The standard insertion losses presented in Figures 8 and Table 2 and labelled 'ISO Class' are derived from measured data for a traditional mineral wool/metal cladding insulation system. These are used as a benchmark for other types of pipeline acoustic insulation systems, including those systems based upon elastomeric and polymeric materials. All the results presented were from measurements taken on cast iron pipe sections having outside diameter of 323mm.

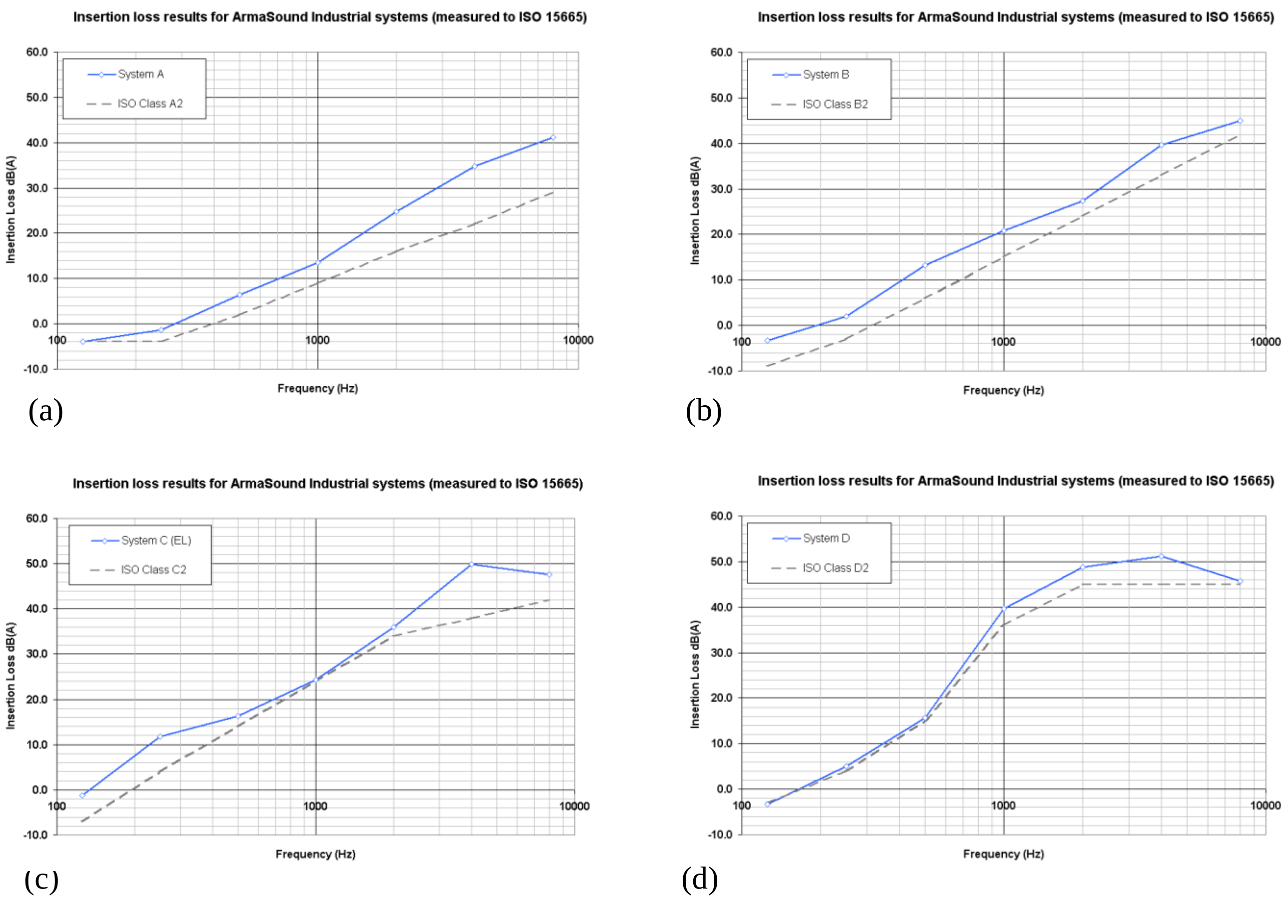

Figure 8: Octave band insertion loss performance of the 4 sandwich systems; (a) System A, (b) System B, (c) System C and (d) System D.

The results in Figures 8 show that in all cases, the ArmaSound Industrial Systems composite meets or exceeds the requirements of the respective classification in each of the octave bands. Moreover, when calculating the broadband insertion loss values for a given noise source, (Table 2), all the values once again exceed the expected performance of the particular classification. In addition to the improved acoustic performance of elastomeric materials, they also offer high insertion loss values with often a much thinner and lighter, elastomeric insulation system compared to equivalent traditional fibrous/metal cladding systems of greater mass. As an example: a 52mm thick, 10.6kg/m^2 surface density class B elastomeric insulation system can offer greater insertion performance than a traditional 100mm thick, 18.4kg/m^2 density mineral wool and metal cladding system. A comparative performance of the specific systems is presented in Figure 8b.

ISO 15665 Specification/ Performance (dB(A))	Control Valve	Centrifugal Compressor	Centrifugal Pump	Reciprocating Compressor
ISO 15665-Class A2	14	10	4	5
Arma-Chek Sound System A	19	15	7	8
ISO 15665-Class B2	18	14	6	6
Arma-Chek Sound System B	23	19	11	12
ISO 15665 -Class C2	24	20	11	10
Arma-Chek Sound System C	29	24	16	16
SHELL DEP-Class D2	27	22	13	13
Arma-Chek Sound System D	28	24	14	14

Table 2: Broadband insertion loss values (dB) for the ArmaSound Industrial Systems performance in relation to pipe work attached to various noise sources.

5 CONCLUSIONS

The acoustic performance of novel types of elastomeric insulation composites has been studied in the laboratory and tested independently to ISO 15665 [2]. It has been shown that a combination of closed and open cell flexible foams offers improved insertion loss values over typical fibrous and metal cladding pipe insulation materials. The introduction of an elastic, open cell product between two impervious layers results in the increase in the measured insertion loss performance. The results of these tests show that each system conforms to the classifications given in the ISO standard. It can be shown that the calculated broadband insertion loss performance of all 4 systems are significantly higher than those based on traditional mineral wool and metal cladding construction according to the ISO 15665 standard.

The combination of closed and open-cell technology, with an additional barrier covering, offers significant benefits to noise control engineers, specifiers and contractors. In particular, these include high thermal and acoustic performance with the reduced risk of under insulation and galvanic corrosion. The acoustic performance can be achieved with the thinner and lighter insulation system. The result of this work demonstrates that elastomeric insulation materials can provide a suitable alternative to mineral wool/metal cladding systems currently used in the marine and offshore segments.

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