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Development of a thermally insulating vibration damping compound

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ABSTRACT

Attenuating vibration in structures, such as marine vessels and rail carriages, through the use of damping materials can return a wide range of benefits from reducing air-borne and structure-borne noise to improving component life. Thermal insulation is typically also installed alongside vibration damping materials, preventing condensation and the transfer of thermal energy, therefore improving energy efficiency and the comfort of passengers and crew, along with increasing component life through the reduction of moisture. This paper details the development and evaluation of a single material, Decicoat T35, which is both vibration damping and thermally insulating, allowing easier and faster treatment over traditionally installing multiple materials. The compound is water-based, non-toxic and easily sprayable. The material has been evaluated to EN 12664 for thermal conductivity and to an internally developed method for anti-condensation in rail and marine industries. Decicoat T35 was also investigated using a variety of methods for vibration damping, including dynamic mechanical analysis (DMA) to ISO 6721-5 and experimental modal analysis (EMA). Furthermore, vibration damping performance was compared to a similar competitors sprayable thermal compound, highlighting the elevated vibration damping properties of the newly developed material. A thermally insulating vibration damping compound was successfully developed and evaluated.

Keywords: Vibration, Damping, Insulation

1. INTRODUCTION

Vibration in structures can be associated with a variety of undesirable effects ranging from structure-borne and air-borne noise to accelerated structure and component fatigue. Several design considerations exist to counter vibration. Typically, application of vibration damping materials could be considered lower in the hierarchy of controls, however if vibration cannot be controlled through structural design choices, then adding vibration damping materials is a viable solution. System vibration damping can be effectively improved by applying a material with high damping characteristics in contact with the vibrating components. These materials primarily achieve damping through their viscoelastic properties, allowing the mechanical energy to be dissipated into heat during deformation of the material (1, 2).

Commonly, damping is represented by the loss factor (η), which is a measure of the energy loss per cycle of deformation. This property depends on the temperature and frequency. These conditions can vary significantly depending on the vibration damping issue, hence it is of interest to understand how the damping properties of different materials compare at a range of temperatures and frequencies. The loss factor of viscoelastic damping materials can be determined through several test methods. One such test is dynamic mechanical analysis (DMA), which measures tan delta (tan δ), a representation of loss factor as a property of the stress-strain response. The DMA method can measure the tan δ of a material over a wide range of temperatures and frequencies, typically -150 to 500 °C and 0.001 to 200 Hz, although an even broader range can be analysed using time-temperature superposition (TTS) and represented as a reduced-frequency nomogram (3).

Another method is experimental modal analysis (EMA), which allows the study of the modal parameters such as natural frequencies/modes and damping factors of a system (4). The damping factors are typically represented as damping ratio ζ (%) or loss factor η, which are calculated using the half power method (5). The primary difference between the DMA and EMA method is that DMA directly tests the properties of a material and EMA tests the properties of a system. Although testing over a temperature range is more challenging than DMA measurements due to the typically larger

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sample sizes, EMA measurements over a temperatures range is possible by changing the temperature of the entire system, such as mounting the system within an environmental chamber.

Constructions lacking adequate thermal insulation can possess a range of issues due to an excessive transfer of thermal energy through boundaries that separate environments. The problems can range from a lack of power efficiency due to the extra energy required for temperature regulation, to formation of condensation, which can cause damage including corrosion. A variety of methods can be utilised to measure several thermal properties of a material. Most commonly measured is the thermal conductivity value, which is a measure of a materials ability to conduct heat. However, measuring a materials ability to resist condensation when applied to a system is not as standardised, but multiple valid approaches can be made to test this.

Decicoat T35 is a water-resistant sprayable water-based compound with EC certification (MED B and D) that exhibits both effective viscoelastic vibration damping and thermal insulation properties. Extensive research and development was conducted to arrive at the final formulation, involving the evaluation of many polymers, fire retardants, fillers and additives. This paper evaluates both the thermal and vibration damping properties of the material.

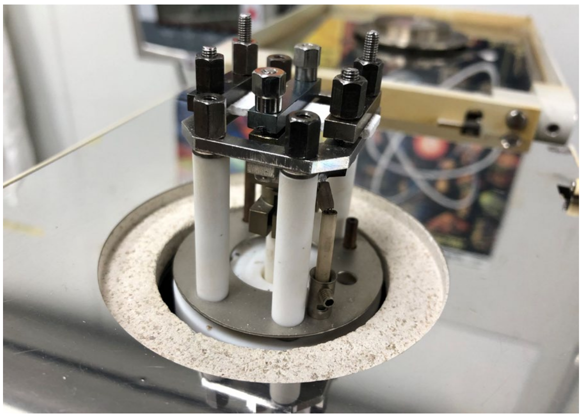
2. METHODOLOGY

2.1 Dynamic Mechanical Analysis (DMA)

A Rheometric Scientific DMTA-3E was used for all measurements. The testing procedure was based on ISO 6721-1:2019 (6). The surrounding environmental conditions were kept stable and consistent, including isolation from external vibration. Liquid nitrogen fed from a pressurised dewar and the internal oven were used to modulate the test chamber temperature, with a filtered flow and pressure controlled air system for convection. Temperature was measured using an internal platinum resistance thermometer (PRT), positioned close to the specimen within the chamber. In aid of thermal equilibrium, the specimen was allowed 30 minutes soak time at the starting temperature before the commencement of testing.

Specimens were cast onto PTFE coated sheeting at a wet film thickness suitable to achieve a dry film thickness of 2 mm (± 0.1 mm). The samples were cut down after adequate curing to the required size for the DMA mounting configuration. Samples were mounted in a dual cantilever configuration using the appropriate frame size, frame clamping, drive shaft clamp and clamping torque for compatibility with the sample’s softer modulus range (less than 1E10 Pa).

Photograph 1 – Rheometric Scientific DMTA-3E



Photograph 2 – Dual-cantilever configuration

A temperature sweep was conducted for both Decicoat T35 and the competitor material. The test was performed over a temperature range of -20 to 50 °C with a ramp rate of 1 °C/min at 1 Hz. A temperature-frequency sweep was also conducted for Decicoat T35 over a temperature range of -15 to 60 °C with an increment of 2.5 °C (5 minutes soak time per temperature step). The frequencies tested were 1, 2, 5, 10, 20 and 30 Hz.

The temperature-frequency sweep data was used to compile a reduced-frequency nomogram. This data was processed by the time-temperature superposition (TTS) module within the TA Orchestrator DMA software in order to create the master curve and calculate the Williams-Landel-Ferry (WLF) equation constants (the WLF equation is stated in equation 1 below) (3). The final production of the reduced-frequency nomogram was executed through a Microsoft Excel template.

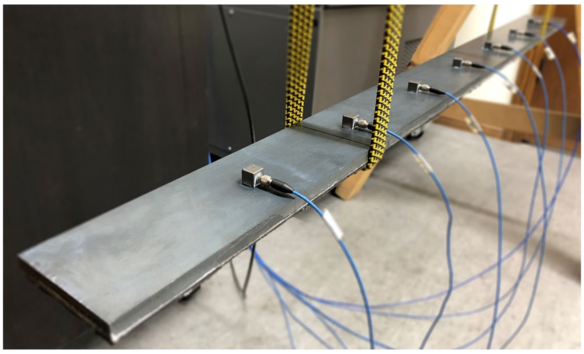
$$\log(a_T) = \frac{-C_1(T - T_0)}{C_2 + (T - T_0)} \quad (1)$$

$\log(a_T)$ = shift factor (dimensionless)
C_1, C_2 = material constants (dimensionless)
T = temperature (K)
T_0 = reference temperature (K)

2.2 Experimental Modal Analysis (EMA)

Due to the lack of an existing standardised method to capture the specific EMA data required for this study, a method was internally developed with influences from MIL-PRF-23653D (7). The developed method utilises a substrate size of 1016 x 76 x 10 mm. Three samples were constructed for testing using mild steel as the substrate material: bare/untreated, Decicoat T35 coated and competitor material coated. The beams were thoroughly cleaned and primed with a suitable primer for adhering water based coatings onto mild steel. The coatings were applied in stages following the manufacturers installation guides, purposely ending at a thickness greater than the final target of 5 mm. After adequate curing, the coatings were machined down to 5 mm (±0.1 mm).

Photograph 3 – Specimen after machining



Photograph 4 – Specimen mounted during EMA testing

The beams were suspended on its flat side (coating facing upwards) by two flexible cords mounted at the nodal points of the first flexural mode of vibration (229 mm in from each end of the beam). A total of 7 accelerometers (PCB Piezotronics TLD333B32) were mounted equidistantly to bare/untreated side of the beam using cyanoacrylate adhesive. The specimens were tested in an environment with a controlled temperature of 23 °C (± 2 °C) and humidity of 50% (± 10%) after a soak time of 3 hours. The samples were impact excited using a PCB Piezotronics TLD086D05 modal impact hammer, utilising a rubber impact tip for modes ≤200 Hz, a nylon impact tip for modes >200 Hz to <2000 Hz and a metal impact tip for modes ≥2000 Hz. Testing was conducted with a bandwidth of 4096 Hz and 16384 spectral lines, resulting in a resolution of 0.25 Hz. The frontend system was a Siemens LMS Scadas, with Siemens Simcenter Testlab and Siemens Polymax software used for all testing, processing and analysis.

2.3 Thermal Conductivity and Anti-Condensation

Thermal conductivity was measured at an external laboratory to the EN 12664:2001 standard (8). The average thermal conductivity of 3 samples was measured in W/(mK) at a mean temperature of 10 °C.

The anti-condensation abilities were measured using an internally developed method, due to the lack of a currently existing standardised method. Samples were mounted over the opening of a temperature modulated chest freezer, allowing temperature differentials as great as 50 °C, where the inside of the freezer was -30 °C and the ambient temperature above the samples was 20 °C. Testing was conducted at 20, 30, 40 and 50 °C differentials, with measurements taken hourly over 3 hours and averaged. The temperature within and outside the chest freezer along with the relative humidity was monitored and recorded. A fan was mounted within the freezer to promote air circulation. All specimens were constructed using 1 mm thick aluminium as the substrate. A bare/untreated sample was measured along with Decicoat T35 treated samples with 1, 2, and 4 mm thick coatings. Formation of condensation was measured using an analytical balance with an accuracy of ± 0.1 mg and expressed as a proportional increase relative to the samples surface area, measured as $g/m^2/hr$.

3. RESULTS AND DISCUSSION

3.1 Dynamic Mechanical Analysis (DMA)

Figure 1 is a DMA temperature sweep (tan δ against temperature) of Decicoat T35 and the competitor material.

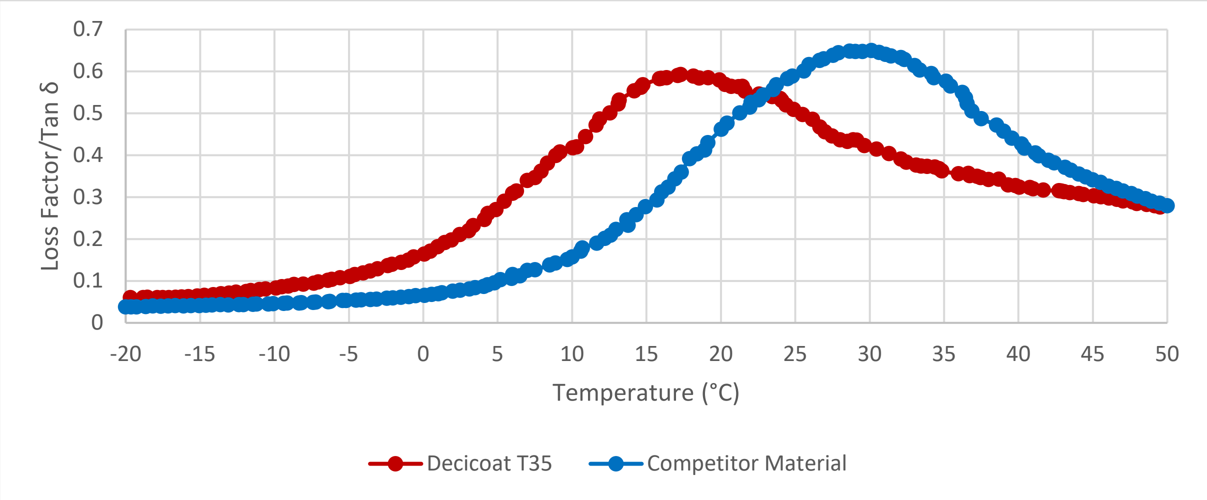


Figure 1 – DMA temperature sweep of Decicoat T35 and the competitor material

The DMA temperature sweep data shows that although the competitor material recorded a higher peak tan δ of 0.65 compared to the 0.59 tan δ measured for Decicoat T35, the T_g of the competitor material is higher at 30 °C, whereas Decicoat T35 recorded a T_g of 17 °C. Based on this data alone, it can be stated that Decicoat T35 will exhibit higher damping at and below standard ambient temperatures. However, depending on the frequency, Decicoat T35 will still exhibit higher damping than the competitor material at temperatures above 22 °C due to the effect of frequency on viscoelastic materials (3). This is demonstrated by the DMA temperature-frequency sweep data for Decicoat T35 in figure 2 below.

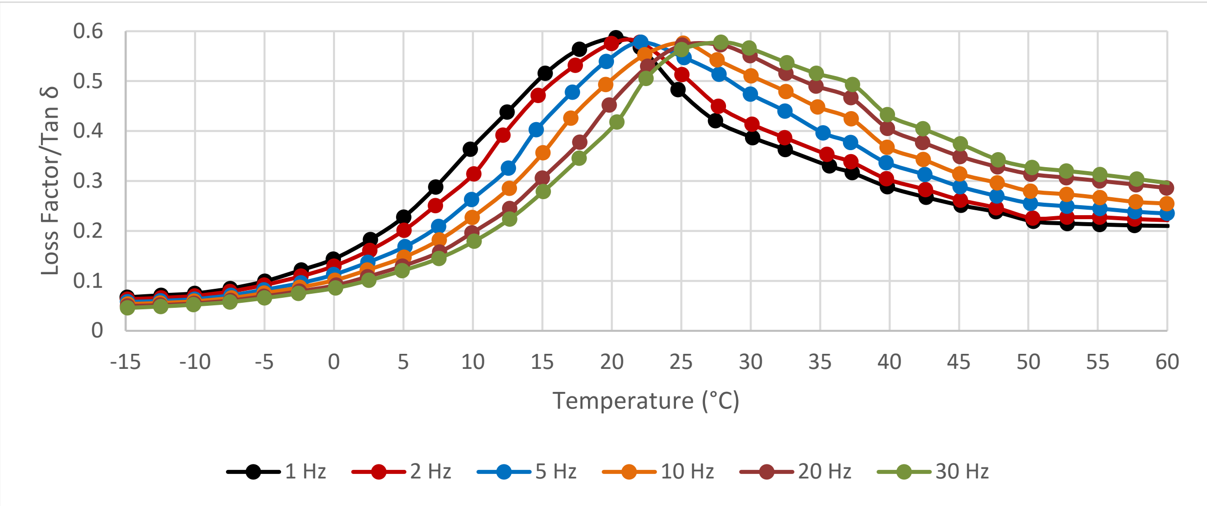


Figure 2 – Decicoat T35 DMA temperature-frequency sweep

Converting figure 2 into a 3D surface plot in figure 3 below gives another representation of the effect of frequency and temperature to the tan δ of Decicoat T35.

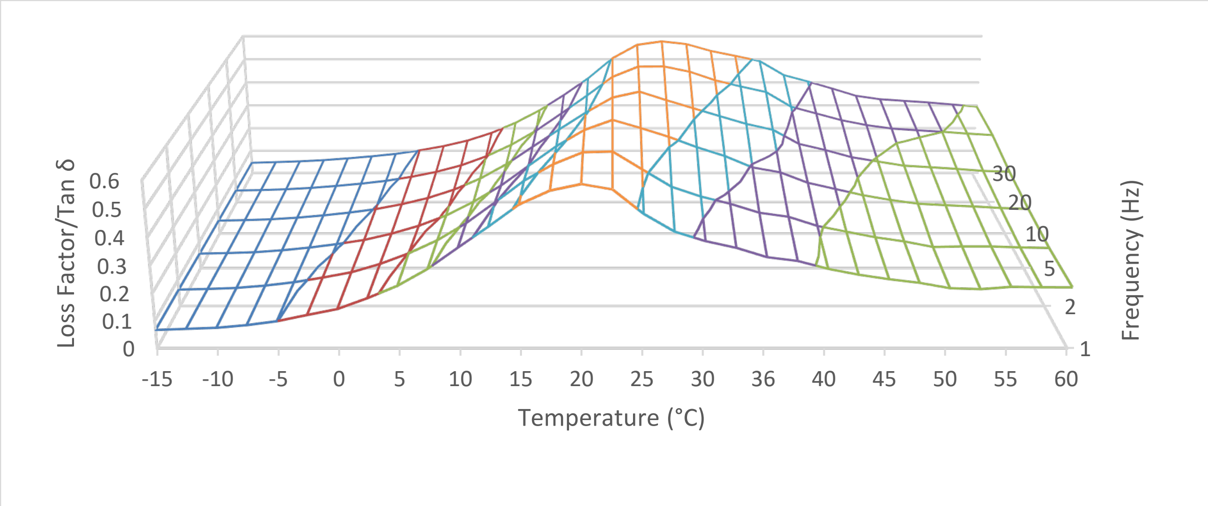


Figure 3 – 3D surface plot of Decicoat T35 DMA temperature-frequency sweep

By utilising the DMA temperature-frequency sweep data and time-temperature superposition (TTS), a reduced-frequency nomogram was created for Decicoat T35 (figure 4 below). This allows the analysis of the loss factor (tan δ) and storage modulus (dyn/cm^2) over a larger than tested range, including outside of the limits of what can be tested using DMA (3, 9). The nomogram utilised a temperature range of -20 °C to 70 °C and a frequency range of 1 Hz to 10 kHz.

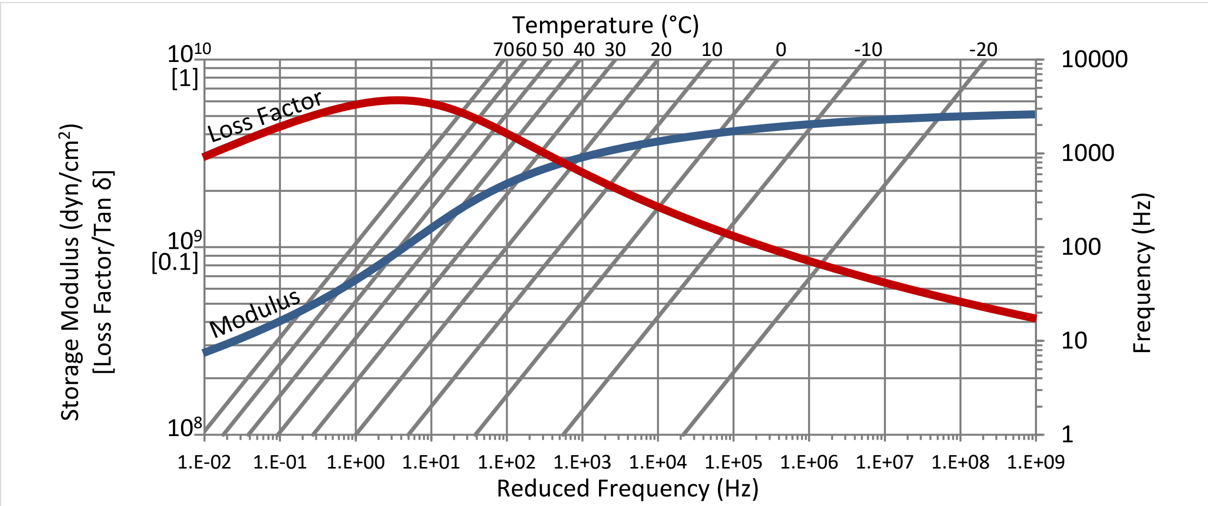


Figure 4 – Reduced-frequency nomogram for Decicoat T35

3.2 Experimental Modal Analysis (EMA)

The EMA test results are divided into two sections: the frequency response functions (FRF) (3.2.1) and the calculated damping values at each mode (3.2.2).

3.2.1 Frequency Response Function (FRF)

As the coatings did not significantly alter the mass or stiffness characteristics of the system, the FRF data overlaps on frequency spectrum for each mode and therefore can be difficult to graphically compare. In order to overcome this for figure 5, the FRF for the competitor material has been shifted by -25 Hz and the FRF for Decicoat T35 has been shifted by 45 Hz. No shift to the amplitude is required.

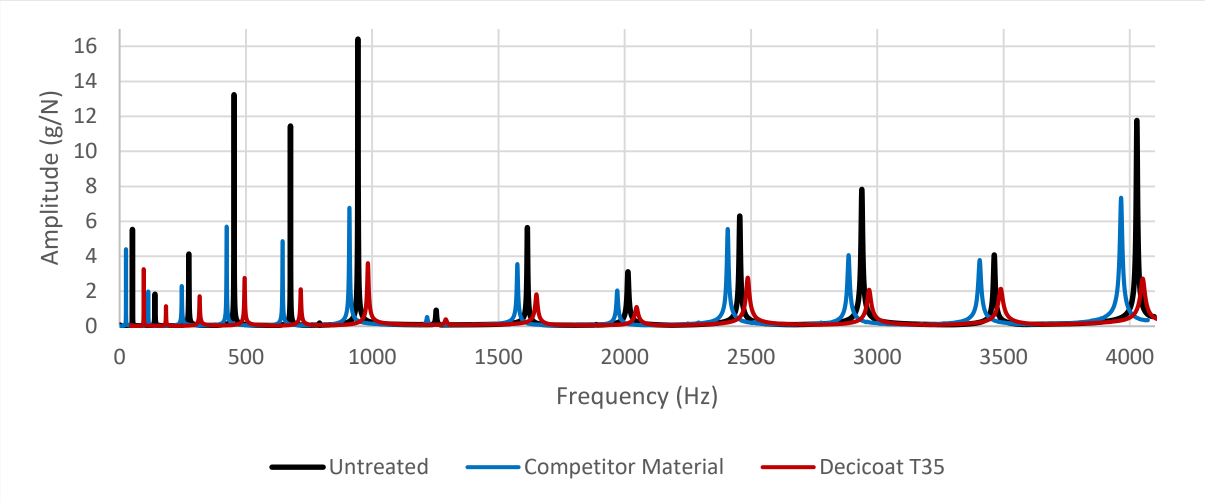


Figure 5 – The FRF data (after frequency shifting – competitor material by -25 Hz, Decicoat T35 by 45 Hz)

Analysing the FRF data alone before any deeper analysis already highlights the contrast in damping between the three systems, with the untreated system expectedly returning the worst damping performance and the Decicoat T35 system returning the highest damping performance. Focusing in on one of the modes better reveals the quality difference of the peaks, rather than just the amplitude difference that the full FRF view provides. For this purpose, the mode at approximately 450 Hz has been isolated in figure 6 below (the shift from figure 5 has been eliminated for figure 6 as it is not required at this resolution).

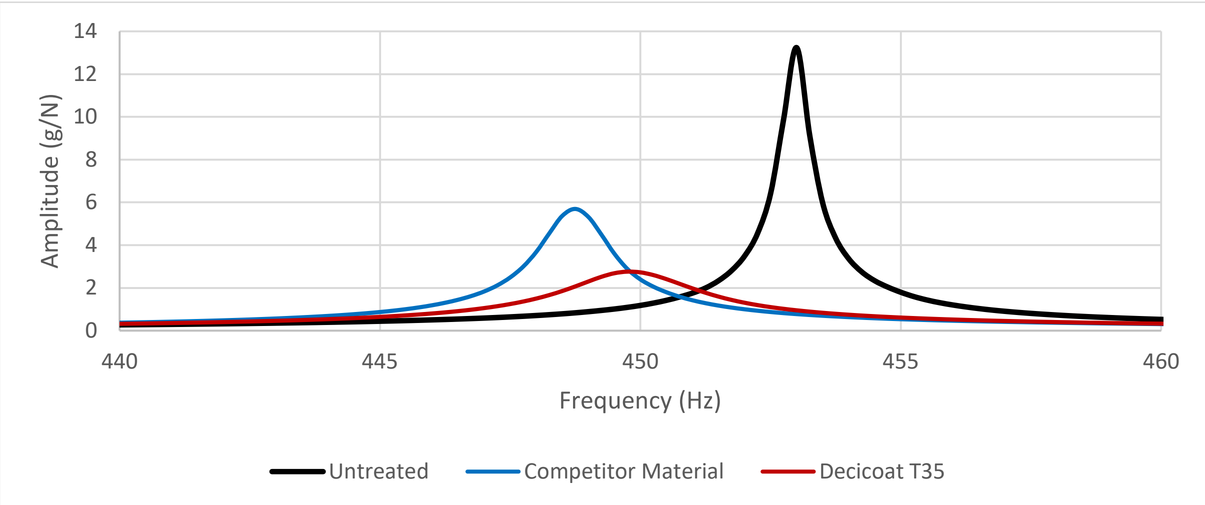


Figure 6 – Focusing in on the mode at approximately 450 Hz

The significant difference between the three systems is highlighted in this view. At this mode, the untreated system achieves a damping ratio ζ of 0.05%, the competitor material achieves 0.12% and Decicoat T35 achieves 0.25%. The relatively minor frequency shift is also visible in this view, with the competitor material displaying the largest shift due to the higher density.

3.2.2 Calculated Damping

The damping ratio ζ (%) and loss factor η have been calculated from the FRF data and presented in table 1 and figure 7 below.

Table 1 – Calculated damping values for each system

Average Frequency (Hz)	Untreated		Competitor Material		Decicoat T35	
	Damping Ratio ζ (%)	Loss Factor η	Damping Ratio ζ (%)	Loss Factor η	Damping Ratio ζ (%)	Loss Factor η
50	0.05	1.1E-3	0.14	2.9E-3	0.22	3.8E-3
139	0.2	4.0E-3	0.16	3.2E-3	0.29	5.4E-3
272	0.14	3.1E-3	0.31	5.8E-3	0.41	7.7E-3
451	0.05	9.2E-4	0.12	2.6E-3	0.25	5.0E-3
673	0.03	5.0E-4	0.1	1.9E-3	0.23	4.4E-3
939	0.06	1.1E-3	0.15	2.8E-3	0.27	5.4E-3
1247	0.12	2.2E-3	0.19	4.0E-3	0.31	6.1E-3
1606	0.08	1.5E-3	0.14	2.7E-3	0.26	5.2E-3
2003	0.14	2.7E-3	0.15	2.9E-3	0.28	5.5E-3
2443	0.1	1.9E-3	0.13	2.5E-3	0.24	4.8E-3
2924	0.09	1.8E-3	0.15	2.9E-3	0.25	4.9E-3
3446	0.08	1.6E-3	0.15	2.9E-3	0.24	4.7E-3
4008	0.06	1.1E-3	0.11	2.2E-3	0.21	4.1E-3

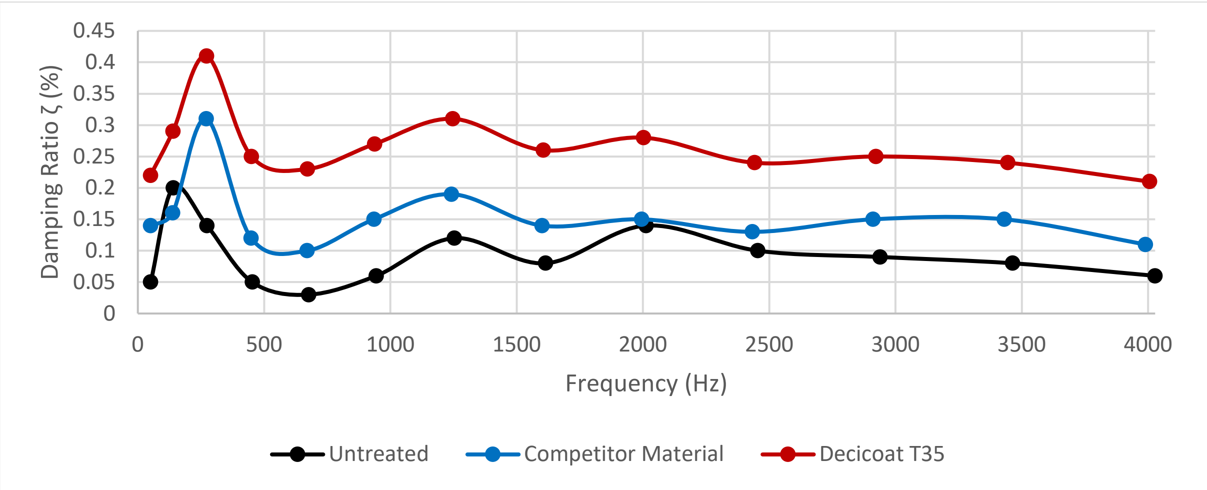


Figure 7 – The calculated damping ratio ζ (%) plotted against frequency (Hz) graphed for each system

There is a minimal change in the frequency of each mode due to the relatively insignificant difference in mass (<2% increase) and stiffness introduced by the coatings. However, there is a significant difference in damping. In this system and environment, Decicoat T35 significantly increases damping over the untreated beam and outperforms the competitor material across the entire measured frequency range with an average η difference of 54%. The greatest η difference of 82% was recorded between Decicoat T35 and the competitor at the mode existing at approximately 670 Hz, and the smallest η difference was 27% at 50 Hz, which can still be considered as significant.

3.3 Thermal Conductivity and Anti-Condensation

Decicoat T35 recorded an average thermal conductivity value over 3 samples of 0.0706 W/(mK) at a mean temperature of 10 °C. This is a positive result for this grade of material that is in alignment with expectations. Very few competitors of this material type state any form of a thermal conductivity value on their technical literature, rendering comparisons difficult.

The anti-condensation results showed Decicoat T35 to be effective at reducing condensation, displayed in figure 8 below. As expected, the amount of measured condensation increased relative to the temperature differential. Thicker applications resulted in a greater difference, with a 1 mm coating recording a difference in condensation by an average of 111% over the tested temperature differential range. The 2 mm coating recorded 122% and the 3 mm coating recorded 154%. The greatest difference was measured with a 3 mm coating at 40 and 50 °C differentials with an average difference of 167%.

It is also notable that the relationship between the moisture condensation rate and the temperature differential is non-linear, as is the relationship between the coating thickness and moisture condensation rate.

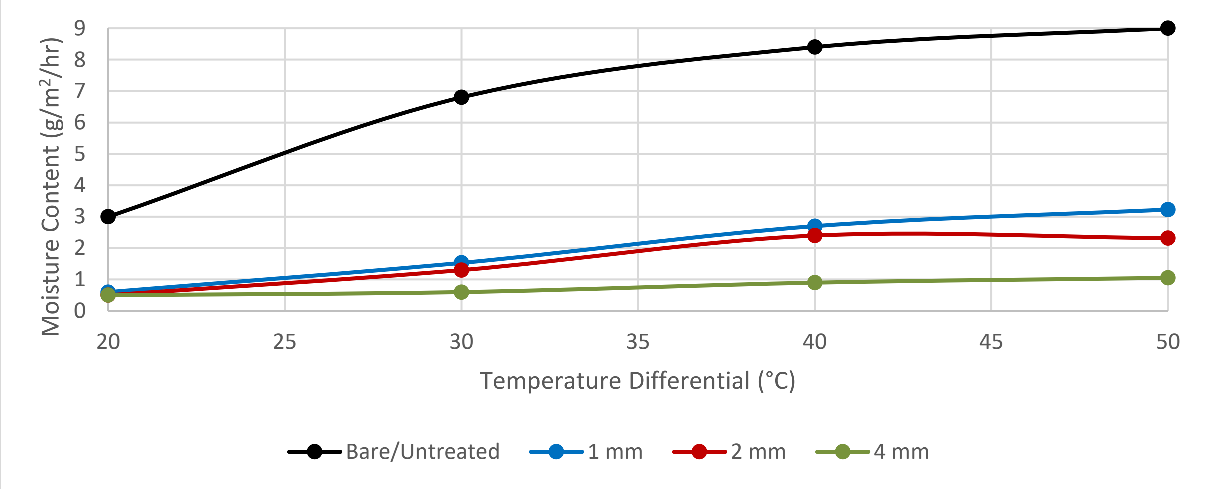


Figure 8 – The measured condensation across several temperature differentials and coating thicknesses

4. CONCLUSIONS

Vibration damping and thermal materials are often used in conjunction within structures such as rail carriages and marine vessels. Decicoat T35 has been designed to exhibit both vibration damping and thermal insulation properties to provide a single solution for both treatment types. It has been evaluated for its vibration damping performance and compared to a similar competitor product, with results revealing that it is an effective damping material with superior performance over the competitor product. It was also tested for its thermal properties, including anti-condensation. Thermal testing showed that the material exhibits low thermal conductivity and effective anti-condensation properties.

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REFERENCES

1. Verstappen AP, Pearse JR. Evaluation of Viscoelastic Vibration Damping Properties with a Dynamic Mechanical Analyzer. 18th International Congress on Sound and Vibration; 10th-14th July 2011; Rio de Janeiro, Brazil 2011. p. 2.
2. Nashif AD, Jones DIG, Henderson JP. Vibration Damping. England, UK: John Wiley & Sons Ltd.; 1985. p. 67-68.
3. Menard KP. Dynamic Mechanical Analysis Second Edition. Boca Raton, USA: CRC Press; 2008. p. 145-168.
4. Piersol AG, Paez TL. Harris' Shock and Vibration Handbook Sixth Edition. New York, USA: The McGraw-Hill Companies Inc.; 2010. p. 21.1-21.5.
5. Jones DIG. Handbook of Viscoelastic Vibration Damping. England, UK: John Wiley & Sons Ltd.; 2001. p. 14-17.
6. International Organization for Standardization 2019, Plastics – Determination of dynamic mechanical properties – Part 5: Flexural Vibration – Non-resonance method, ISO 6721-5:2019, International Organization for Standardization, Geneva.
7. Department of Defence 2009, Performance Specification: Plastic Tiles, Vibration Damping, MIL-PRF-23653C, Department of Defence, Philadelphia.
8. European Committee for Standardization 2001, Thermal performance of building materials and products – Determination of thermal resistance by means of guarded hot plate and heat flow meter methods, EN 12664:2001, European Committee for Standardization, Brussels.
9. Holgate P, Rasa A. Optimisation of a viscoelastic damping material using dynamic mechanical analysis. WMTC 2015; Rhode Island, USA, 3rd-7th November 2015. p. 11.