Advancements in Polyamide-Based Anti-Vibration Systems for Automotive Engineering

Exploring Novel Materials and Solutions

Introduction

The level of noise experienced in a vehicle is often inversely related to its perceived value. Simultaneously, automakers continue to focus on improving energy efficiency in the development of new vehicle platforms, with reductions in vehicle weight often the preferred method to improving efficiency.

Thermoplastics are cost-effective and lightweight alternatives to metals and have been extensively researched for use in anti-vibration systems for over a decade. As the automotive industry transitions towards hybrid and fully electric vehicles, energy efficiency and system noise and vibration have gained attention.

Anti-vibration components are critical for mitigating undesirable vibrations, thereby enhancing overall system performance. The development of light-weight thermoplastics capable of replacing structural components holds considerable promise for achieving significant improvements in vibration reduction. This paper focuses on the development of a novel polyamide material designed specifically for structural components, offering a unique balance of mechanical strength and damping performance.

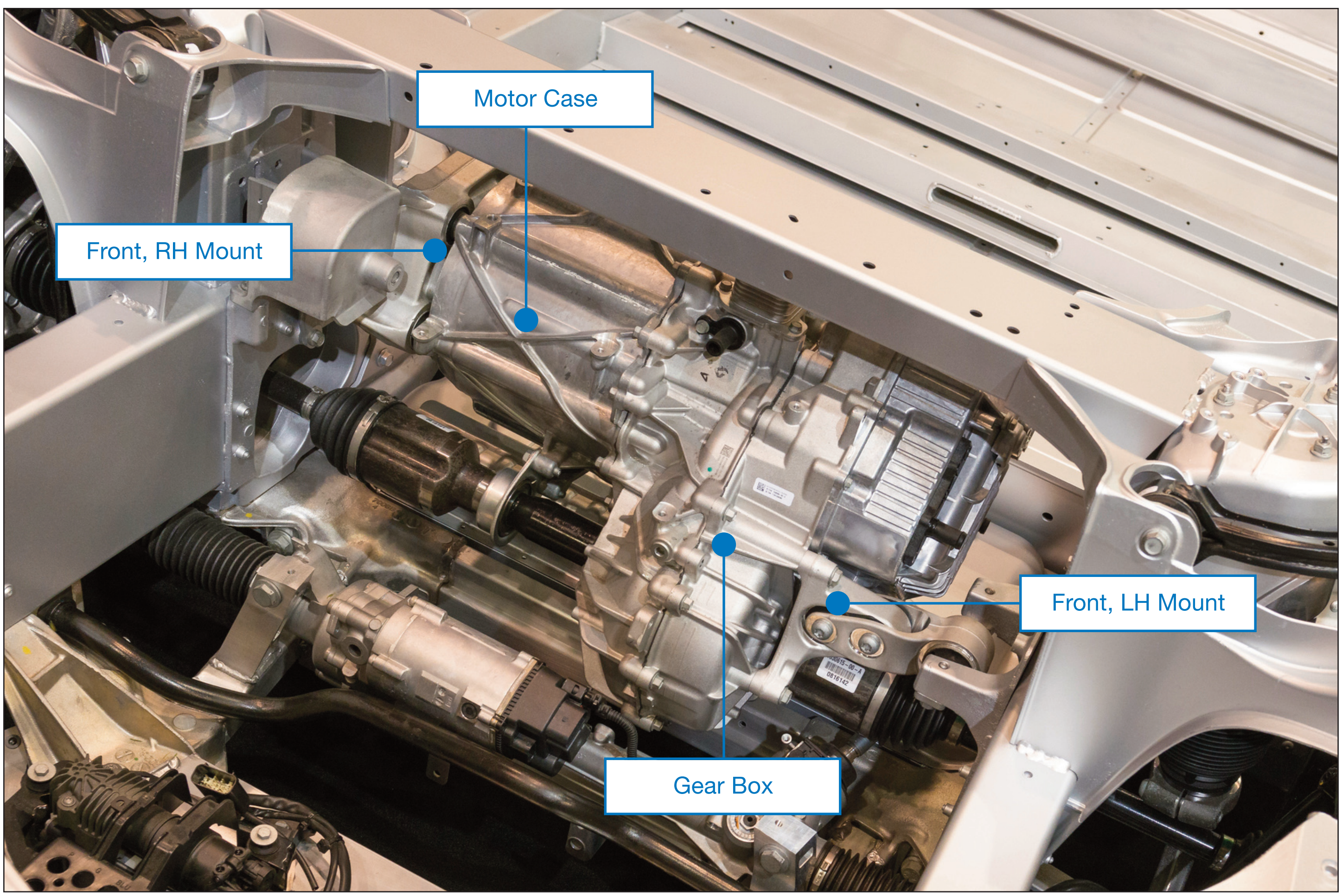
This novel polyamide material is made by utilizing both additive technology, as well as tailoring the polymer backbone. Depending on the modifications, different grades can target specific frequency ranges and operating temperatures, an important characteristic as electric vehicles change the automotive landscape.

Traditional Approach to Automotive Vibration

Vibration, defined as the oscillation of a moving object around an equilibrium point, poses a significant challenge in automotive applications. Sources of vibration such as road roughness, engine unbalance, and rotating shafts contribute to increased noise levels and energy loss. Over time, anti-vibration systems (AVS) have evolved to mitigate mechanical vibrations and reduce vehicle noise. Engine and motor mounts exemplify AVS components designed to offer several benefits to vehicles (see Figure 1). These mounts stabilize engine or motor devices during operation or stationary periods, and provide isolation against structure-borne noise.

In conjunction with efforts to minimize noise and vibration, advancements in materials science play a pivotal role in automotive engineering. Innovations in composite materials offer a promising avenue for reducing the weight of vehicle components without compromising structural integrity. Lighter materials not only contribute to enhanced fuel efficiency but also aid in attenuating vibration levels by dampening resonant frequencies more effectively. Moreover, the design of engine and motor mounts undergoes continuous evolution to ensure optimal performance and durability. Engine mounts, for example, are meticulously engineered to withstand the dynamic forces generated by the power-train while effectively isolating vibrations from the vehicle chassis. By integrating advanced materials and innovative design features, these mounts play a crucial role in enhancing both the mechanical robustness and acoustic comfort of modern vehicles.

Figure 1. EV powertrain



The design of engine and motor mount systems considers various factors such as vehicle dynamics and crash scenarios. Rubber isolators, positioned between structural brackets attached to the engine and the vehicle, form a crucial component of these systems (see Figure 2). By decoupling the engine and vehicle sides, rubber isolators dissipate a significant portion of structure-borne noise through internal damping mechanisms.

Conventional AVS, including engine mounts, predominantly rely on rubber for vibration damping. This reliance has led to the development of diverse rubber formulations capable of withstanding various load conditions and temperature ranges.

Structural brackets, typically constructed from steel or aluminum, provide stability but do not actively contribute to vibration isolation. However, driven by the need for enhanced fuel efficiency due to the lower weight of plastic materials compared to metals, recent advancements have seen efforts to replace metal brackets with thermoplastic alternatives.

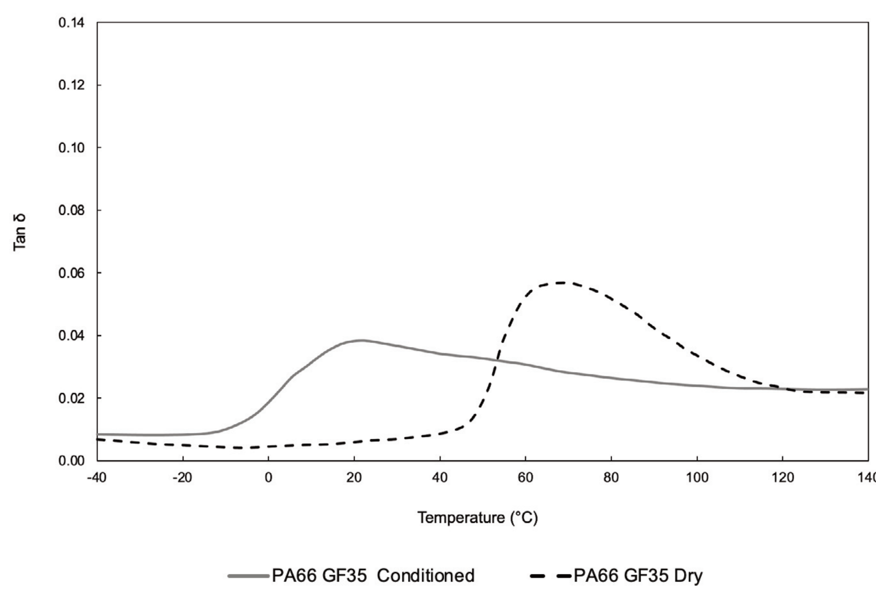
The adoption of thermoplastics in structural brackets has been facilitated by a deeper understanding of their material properties and failure mechanisms. Finite element analysis (FEA) methods have enabled the prediction of thermoplastic component performance. Notably, structural brackets made from thermoplastics can actively contribute to vibration damping due to the inherent properties of the polymeric matrix.

For nearly a decade, the industry has successfully replaced some metal brackets with solutions based on thermoplastics. The main driver of this substitution is the demand for higher fuel efficiency facilitated by the lower weight of thermoplastics relative to metals. This trend has been enabled by advanced understanding, via FEA, of thermoplastic materials and their failure mechanisms.

Structural brackets made of thermoplastics can actively contribute to vibration damping by leveraging the unique characteristics of the polymeric matrix. The damping intensity and temperature range are intricately linked to the chemical composition of the polymer. For instance, Figure 3 demonstrates the damping behavior of a standard PA66 with 35% short glass fibers. The peak tan δ, a measure of material internal damping, exhibits values of approximately 0.06 in dry as molded (DAM) and 0.04 in relative humidity of 50% (RH50) conditions, respectively. Additionally, the glass transition temperature (Tg), marking the point of peak damping, is approximately 70°C and 20°C in DAM and RH50 conditions, respectively. Despite these promising characteristics, the damping effect of thermoplastics in structural bracket design has yet to be extensively explored. Further research is warranted to fully harness the potential of thermoplastics in enhancing vibration damping properties within automotive applications.

Figure 2. Engine mount (Chevy Malibu)
Images courtesy of A2MAC1

Figure 3. Damping behavior of a standard PA66



The Significance of Vibration Damping in Automotive Applications

In internal combustion engine vehicles, auxiliary drives such as water pumps and air compressors are typically mounted to the engine block and driven by the engine via a belt (see Figure 4). In this arrangement, the engine mount system absorbs vibrations from the water pump or air compressor, necessitating only an adaptor bracket for mounting onto the engine block. However, this setup results in continuous operation of auxiliary drives, even when not required, leading to additional fuel consumption during idle periods.

To enhance fuel efficiency, modern vehicles have detached auxiliary drives from the engine block, powering them with individual electrical drives (see Figure 5). This allows for independent activation and deactivation of drives, which optimizes energy consumption. Moreover, the repositioning of these units within the vehicle according to system requirements offers added benefits. For instance, integrating the coolant pump with major coolant flow control valves and situating the HVAC compressor near heat exchangers streamline operations. Consequently, these drives necessitate their own mount systems with anti-vibration system (AVS) features to mitigate vibration and noise generated by the water pump or HVAC compressor throughout the vehicle.

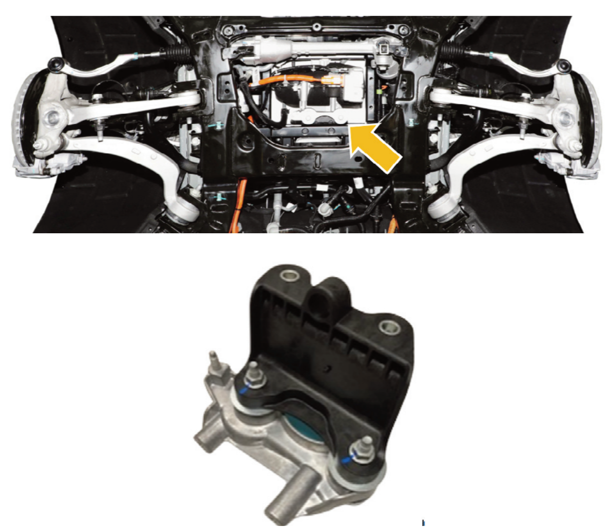
The emergence of electric vehicles (EVs) has raised expectations regarding noise and cabin quality. While electric drives are quieter than internal combustion engines (ICEs), previously unnoticed noises from auxiliary drives become more audible in EVs. Additionally, electric drives produce vibrations at higher frequencies and lower acceleration levels compared to ICEs. Components unique to EVs, such as power electronics in inverters, contribute to vibration and noise, requiring attention to AVS across various vehicle units and drives.

Furthermore, the high-speed rotations of electric motors can generate high-frequency airborne noise, posing challenges to creating a comfortable driving environment. Airborne noise, transmitted through the air and audible in the cabin, is influenced by the high-speed rotations of powertrain components and associated drivetrain elements in EVs.

Frequencies associated with passenger discomfort, typically ranging from 800 Hz to 3600 Hz, can resonate with the cabin's natural frequencies, amplifying their perceptibility and causing discomfort among occupants. These frequencies align with the mid to high-frequency spectrum, where human hearing is most sensitive.

Figure 4. Engine assembly of the Volkswagen Atlas V6 featuring a belt-driven HVAC compressor.
Image courtesy of Caresoft

Figure 5. HVAC compressor with separate mount system in the GM Cadillac EV Lyriq
Image courtesy of Caresoft



Introducing a Novel Approach to Anti-Vibration Systems (AVS)

When examining the conventional methods employed in AVS, the question arises as to whether the structural bracket could play a more active role in vibration damping, rather than merely serving as a passive element. Structural components typically possess greater volume compared to rubber isolators, and the propagation path across them is often longer than that across rubber isolators. Moreover, rubber isolators tend to be more effective against low-frequency vibrations than higher-frequency noises.

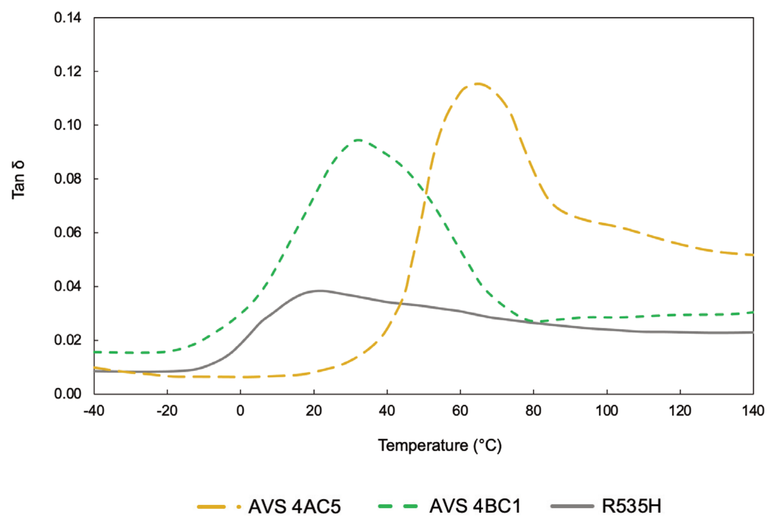
An ideal scenario would involve a material that combines desired mechanical properties for structural components with advanced internal damping capabilities. The internal damping of thermoplastics, typically expressed as tan δ and measured through DMA tests, is crucial in this context. The temperature at which maximum peak value of tan delta occurs is often indicative of the glass transition temperature (Tg) of a polymer, representing the temperature at which the polymer transitions from a glassy to a rubbery state. With increased temperature, the long-range motion of polymeric chains also intensifies.

As discussed earlier, a standard PA66 with 35% short glass fiber reinforcement exhibits internal damping dependent on temperature, offering a maximum tan δ value of 0.04 at 20°C under RH50 conditions (see Figure 6, solid gray line). To contribute effectively to the anti-vibration aspect of a mount system, novel polyamide (PA) materials must exhibit higher internal damping than standard PA66.

Comparative analysis of tan δ values for standard PA66 and the novel PA under RH50 conditions is depicted in Figure 6. These data, derived from temperature sweep flexural DMA tests conducted at a frequency of 1Hz, demonstrate that the novel PA material with 35% short glass fiber (Vydyne® AVS 4AC5) provides a peak tan δ of >0.1, doubling that of standard PA66. Furthermore, the temperature at which the peak tan δ occurs shifts approximately 40°C to the right for the novel PA compared to standard PA66.

The tan δ for the novel PA significantly exceeds that of standard PA66 material, while the temperature at which peak damping performance occurs falls within the main temperature range for most AVS applications, typically 40-80°C. Given the hygroscopic nature of polyamide materials, investigating damping performance at RH50 conditions within this temperature range is logical.

Figure 6. Vydyne® AVS Tan Delta - GF35%, RH conditioned



The air compressor bracket in the GM Cadillac Lyric (see Figure 5) is made out of Novel PA66 with 35%GF, a decision driven by its significant contribution to noise reduction for original equipment manufacturers (OEMs). This innovative use of materials underscores the importance of considering both material properties and environmental factors in the pursuit of optimal noise reduction strategies within automotive design.

In general, two approaches exist to intentionally shift the tan δ (or Tg) of a material into a desired range. The first involves chemically altering the polymer to enhance stiffness, though this may impact the material's physical properties. The second approach utilizes physical blends of miscible polymers, offering a more economical solution with minimal impact on physical properties.

An essential consideration in this development is maintaining the structural performance of the part or component. The mechanical properties of the thermoplastic must not be significantly affected by improvements in damping functionality, presenting a complex problem to solve. Traditional methods to enhance energy absorption often compromise material strength or stiffness.

Table 1 provides a relative overview of standard PA66 and several Novel PA (both with 35% short glass fiber), including physical, mechanical, thermal and damping characteristics at 23°C under DAM conditions. The novel material demonstrates comparable strength and stiffness to standard PA66, with a significant increase in peak tan δ value. While a slight reduction in impact resilience is observed for the novel PA, the values remain within an acceptable range for most AVS applications.

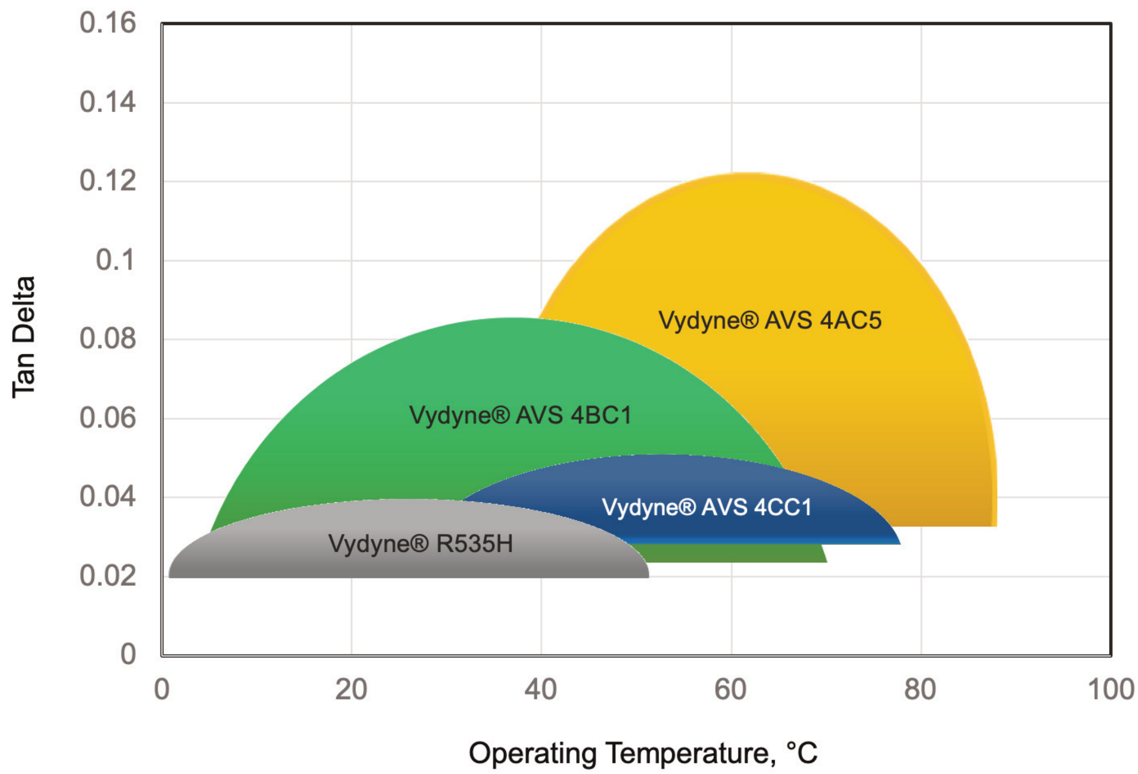
Vydyne® AVS represents a novel approach that provides well-balanced material characteristics suitable for various vehicle structural components. Leveraging polymer backbone technology, Vydyne® AVS offers robust mechanical properties across temperature ranges and provides damping without additional components to mitigate vibration transmission. Vydyne® AVS product portfolio encompasses three types tailored to meet mechanical strength, damping and operational temperature range requirements.

Table 1. Comparative overview of properties between regular PA66 and Novel PAs at 23°C under DAM conditions.

Physical	**Unit**	**Vydyne® R535H BK02**	**Vydyne® AVS 4CC1 BK0888**	**Vydyne® AVS 4BC1 BK0886**	**Vydyne® AVS 4AC5 BK0826**
Density	g/cm^3	1.41	1.42	1.42	1.43
Glass Fiber Content	%	35	35	35	35
Mechanical					
Tensile Modulus (23°C)	MPa	10600 / 8000	11500 / 9300	11500 / 9900	11500 / 11200
Tensile Stress (Break, 23°C)	MPa	212 / 136	199 / 139	197 / 151	189 / 163
Tensile Strain (Break, 23°C)	%	2.9 / 5.5	2.7 / 4.0	2.7 / 3.0	2.5 / 3.0
Flexural Modulus (23°C)	MPa	10500 / 7000	11200 / 8800	11100 / 8700	11100 / 11600
Flexural Strength (23°C)	MPa	300 / 205	292 / 198	287 / 193	260 / 236
Impact					
Charpy Notched Impact Strength (23°C)	KJ/m^2	12 / 14	11 / 12	11 / 11	10 / 9.1
Charpy Notched Impact Strength (-30°C)	KJ/m^2	11 / 12	10 / 9.1	10 / 8.7	9.2 / 8.2
Charpy Notched Impact Strength (-40°C)	KJ/m^2		9.5 / 8.8	10 / 8.6	9 / 8
Charpy Unnotched Impact Strength (23°C)	KJ/m^2	80 / 90	77 / 79	75 / 82	72 / 58
Charpy Unnotched Impact Strength (-30°C)	KJ/m^2	70 / 85	64 / 60	65 / 65	67 / 53
Charpy Unnotched Impact Strength (-40°C)	KJ/m^2		63 / 58	64 / 59	67 / 52
Thermal					
Heat Deflection Temperature (0.45 MPa)	°C	250	247	244	180
Melt Temperature	°C	260	260	260	265
Damping (DMA)					
Tan Delta Peak Temperature (Dry as Molded)	°C	70	90	82	103
Tan Delta at Peak (Dry as Molded)		0.06	0.07	0.12	0.23
Tan Delta Peak Temperature (Conditioned RH50)	°C	22	59	50	64
Tan Delta at Peak (Conditioned RH50)		0.04	0.06	0.07	0.12
Tan Delta at 70°C (Dry as Molded)		0.05	0.04	0.09	0.03
Tan Delta at 70°C (Conditioned RH50)		0.03	0.05	0.06	0.11

For ICE plastic components, where temperatures may exceed 100°C, Vydyne® AVS mitigates vibrations in the low-frequency range, up to 500 Hz, reducing vibration transmission to the chassis. Conversely, EVs may generate high-frequency noise transmitted into the cabin through structural vibration or airborne transmission. Additionally, EV powertrain operating temperatures are considerably lower than ICE vehicles, with motor case housing temperatures maintained at room temperature or up to 70°C, as indicated by various tests and simulations. Figure 7 illustrates the performance of Vydyne® materials concerning damping level and operating temperature. Each material exhibits a specific range of damping capabilities, with peak performance occurring within certain temperature ranges. Identifying the temperature conditions relevant to each application is crucial, enabling the selection of a material whose performance aligns most closely with the required temperature range.

Figure 7. Vydyne® material portfolio at Relative Humidty of 50%



Summary and Conclusions

This paper explores the evolution of anti-vibration systems (AVS) in automotive engineering, marking a transition towards novel materials aimed at improving vibration damping and noise reduction. Initially, AVS relied on rubber isolators and metallic brackets to mitigate vibrations from sources like engines and auxiliary drives. However, with advancements such as the rise of electric vehicles (EVs), the landscape of vibration control has transformed.

The emergence of novel materials, especially thermoplastics, offers a promising avenue for enhancing AVS performance. Leveraging the potential of structural brackets to actively contribute to vibration damping while preserving mechanical integrity, engineers are exploring polymer technology and advanced materials science. The goal is to develop thermoplastics with superior damping properties, enabling effective vibration control across a wider frequency spectrum.

By tapping into the intrinsic damping properties of novel materials like thermoplastics, engineers can craft AVS components that deliver superior vibration control while maintaining structural integrity. The paper emphasizes a holistic approach to AVS design, considering factors like temperature sensitivity, mechanical properties, and damping characteristics.

As automotive technology evolves, AVS will remain pivotal in enhancing vehicle performance, durability, and passenger comfort. Future research efforts may focus on refining material formulations, optimizing component design, and integrating smart technologies to further enhance AVS effectiveness in next-generation vehicles.

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