The 14th ISAV2024 International Conference on Acoustics and Vibration
11-12 Dec 2024 Karaj - Iran
Iranian Society of Acoustics and Vibration
Kharazmi University

Comprehensive Analysis of the Effect of Polyisobutylene (PIB) Molecular Weight on Damping Properties of Butyl-Based Constrained Layer Damping Systems

Atiyeh Amirafshar[a], Zahra Pourakbar[a*]

[a]*Research and Development Expert, Ayegh Khodro Toos Company, North Talash Blvd, Talash Shomali 7/4, 9185177209, Mashhad, Iran.*

[b] *Research and Development Manager, Ayegh Khodro Toos Company, North Talash Blvd, Talash Shomali 7/4, 9185177209, Mashhad, Iran*
* Corresponding author e-mail: *zpourakbar@aktcom.com*

Abstract

This paper investigates the effects of combining high molecular weight polyisobutylene (HMW PIB) and low molecular weight polyisobutylene (LMW PIB) on the performance of butyl-based constrained layer damping (CLD) systems. By formulating a series of PIB blends, this study examines how different combinations of HMW and LMW PIB influence critical mechanical and damping properties for noise, vibration, and harshness (NVH) applications. The results reveal that higher proportions of HMW PIB significantly enhance mechanical and adhesion strength, while increased LMW PIB weight percentage leads to improved damping behaviour, resulting in superior energy dissipation and damping efficiency. Notably, Sample A demonstrates a balanced performance with commendable mechanical integrity and effective damping capabilities. In contrast, Sample B excels in damping properties due to its higher LMW PIB weight percentage, making it ideal for applications requiring optimal NVH control, while Sample C, with its robust mechanical characteristics, shows weaker damping efficiency. This research provides valuable insights for the design and application of advanced damping materials, highlighting the importance of optimizing the combination of HMW and LMW PIB to develop high-performance solutions in the automotive, aerospace, and construction industries, where effective vibration control is essential.

Keywords: Constrained Layer Damping, Butyl Rubber, Polyisobutylene, Noise Vibration Harshness.

1.Introduction

Constrained Layer Damping (CLD) is a widely employed technique in engineering and materials science aimed at reducing vibrations and noise in structures. CLD systems typically consist of a viscoelastic material sandwiched between two stiff substrates, facilitating the dissipation of vibrational energy as heat [1]. The performance of CLD systems is heavily influenced by the properties of the viscoelastic layer, which can be engineered through the selection and combination of constituent materials. In this context, the blending of HMW and LMW PIB presents a promising avenue for optimizing the damping characteristics of butyl-based CLD materials. [2,3].

Polyisobutylene (PIB) is a class of organic polymers prepared by the polymerization of isobutene. These polymers are typically colourless gummy solids. The polymerization is usually initiated with a strong Brønsted or Lewis acid [4]. The molecular weight (MW) of the resulting polymer determines its applications[5,6]. Low molecular weight PIB, consisting of a mixture of oligomers with a number average molecular weight (Mn) of about 1500, is commonly used as a plasticizer. In contrast, medium and high molecular weight PIB, with Mn ≥ 2500, serve as components in commercial adhesives.

The selection of PIB blends is critical for enhancing performance in various applications, particularly in sectors such as automotive and aerospace, where effective noise, vibration, and harshness (NVH) control is vital for ensuring passenger comfort and maintaining structural integrity [7]. The viscoelastic properties of PIB can be optimized by combining HMW and LMW PIB, directly influencing mechanical properties as well as the long-term durability and stability of the resulting composite materials [8]. This tailoring of molecular weight combinations enables the development of PIB blends that meet specific performance criteria, ultimately enhancing their functionality in demanding environments.

Despite the extensive application of PIB, there remains a gap in understanding how different combinations of HMW and LMW PIB affect the overall performance of CLD systems. This research aims to address this gap by investigating the mechanical and damping properties of PIB blends. By analysing the interplay between HMW and LMW PIB, we seek to identify optimal formulations that enhance the structural integrity and damping performance of butyl-based CLD systems. The outcomes of this study will provide valuable insights for the design and implementation of advanced damping materials across a range of industries, ultimately contributing to improved performance and sustainability in engineering applications.

2. Materials, Tests, and Standards

2.1 Materials

The combination of HMW and LMW PIB across the samples is instrumental in tailoring their viscoelastic properties, thereby influencing the mechanical performance and damping characteristics critical for constrained layer damping (CLD) systems. The strategic selection and blending of these molecular weights facilitate the optimization of composite materials to enhance their functionality in demanding applications, particularly in the automotive and aerospace sectors, where effective noise, vibration, and harshness (NVH) control is paramount.

Table 1. Composition of PIB Samples

Sample	HMW PIB (wt%)	LMW PIB (wt%)
A	15	3
B	0	14
C	11	0

2.2 Testing Standards

A basic testing approach was employed to assess the mechanical and damping properties of the formulations. The tests adhered to established standards, ensuring reliability and validity in the results. The following testing protocols were utilized:

- **Adhesion/Peeling Strength:** Measured according to D51 1485 (Peugeot standards), which specifies a minimum pass threshold of 6 MPa. This standard evaluates the bond strength between the damping layer and the substrate, crucial for ensuring material integrity during dynamic loading.
- **Tensile Strength:** Assessed to ensure that the formulations meet the minimum tensile strength using MS373 (Hyundai and Kia standards) requirement of 0.6 MPa. This property is essential for evaluating the material's ability to resist elongation and fracture under load.
- **Penetration:** Tested using D55 1154 (Peugeot standards); this standard evaluates the material's ability to resist the passage of gases or liquids. Moderate penetration is desirable for maintaining the integrity of the CLD system and enhancing adhesion.
- **Damping Factor Measurements:** Conducted according to ASTM E756 for loss factor and D45 1375 (Peugeot standards) for damping factor. The loss factor was measured at frequencies of 100 Hz and 200 Hz, reflecting the material's ability to dissipate vibrational energy effectively.

Through these rigorous testing protocols, this research aims to uncover the mechanisms that contribute to enhanced energy dissipation in CLD systems, providing insights that will guide the development of high-performance materials tailored for the NVH industry.

3. Results and Discussion

This section presents a comprehensive analysis of the mechanical and damping properties of butyl-based constrained layer damping (CLD) samples formulated with different combinations of high molecular weight polyisobutylene (HMW PIB) and low molecular weight polyisobutylene (LMW PIB). Each sample's performance is evaluated based on adhesion strength, tensile strength, penetration, loss factor, and damping factor, as summarized in the tables below.

3.1. Mechanical Properties

Table 2. Mechanical Test Results

Sample	HMW PIB (wt%)	LMW PIB (wt%)	Adhesion Strength (MPa)	Tensile Strength (MPa)	Penetration
A	15	3	14.6	0.63	90
B	0	14	6.85	0.61	95
C	11	0	7.6	0.66	83

The experimental results in Table 2. clearly demonstrate that higher proportions of HMW PIB significantly enhance adhesion strength. For instance, Sample A, containing 15 units of HMW PIB, achieves an adhesion strength of 14.6 MPa, surpassing the minimum required threshold of 6 MPa. The underlying reason for this enhancement lies in the longer molecular chains of HMW PIB, which facilitate greater interlocking and entanglement between the polymer chains and the substrate surface. This leads to stronger intermolecular forces and improved bonding, which are critical in applications where mechanical integrity during dynamic loading is essential [9].

In terms of tensile strength, all samples performed satisfactorily, with Sample C showing the highest tensile strength of 0.66 MPa, demonstrating that the strategic balance of PIB weight percentage effectively supports structural integrity under elongation.

3.2. Damping Properties

Table 3. Damping Factor Measurements

Sample	Damping Factor at 100 Hz	Damping Factor at 200 Hz	Loss Factor (η)
A	0.44	0.42	49
B	0.82	0.46	58
C	0.41	0.36	36

The damping factor measurements presented in Table 3 reveal significant differences in the damping properties of the samples. Sample B, which contains a higher proportion of low molecular weight polyisobutylene (LMW PIB), exhibits the best damping performance, with a damping factor of 0.82 at 100 Hz and 0.46 at 200 Hz. This enhanced performance can be attributed to the lower viscosity and greater mobility of the LMW PIB chains, enabling effective energy dissipation as thermal energy under dynamic loading conditions [10,11]. The higher energy absorption capacity of Sample B indicates its suitability for applications where superior noise, vibration, and harshness (NVH) control is required.

In contrast, Sample C displays weaker damping characteristics, with damping factors of 0.41 at 100 Hz and 0.36 at 200 Hz. The lower damping efficiency of Sample C, which has a relatively lower LMW PIB weight percentage, suggests that it is less effective at dissipating vibrational energy compared to Sample B. Despite these limitations, Sample C maintains a loss factor of 36, indicating some level of energy dissipation, albeit less effectively than Sample B [10-14].

Sample A represents a middle ground between the two, demonstrating balanced mechanical properties while providing moderate damping performance with damping factors of 0.44 at 100 Hz and 0.42 at 200 Hz. This performance highlights the trade-off between mechanical integrity and damping efficiency. The higher weight percentages of high molecular weight polyisobutylene (HMW PIB) in Sample A enhances strength and adhesion but may restrict its ability to dissipate vibrational energy effectively compared to Sample B. Consequently, the results underscore the importance of optimizing the weight percentage of HMW to LMW PIB in developing effective constrained layer damping systems.

4.Conclusion

This study demonstrates how varying the weight percentages of high molecular weight polyisobutylene (HMW PIB) and low molecular weight polyisobutylene (LMW PIB) affects the mechanical and damping properties of butyl-based constrained layer damping (CLD) systems, with important implications for noise, vibration, and harshness (NVH) applications. Sample B, with a higher LMW PIB weight percentage, excels in damping performance, offering the highest damping factors and energy dissipation, making it ideal for advanced NVH control. In contrast, Sample C, characterized by higher HMW PIB, shows stronger mechanical properties but weaker damping efficiency. Sample A, with a balanced composition, achieves a compromise between mechanical strength and damping performance, making it suitable for versatile applications. The study underscores the importance of optimizing PIB weight percentages to develop high-performance damping materials that enhance structural integrity while effectively controlling vibrations and noise, particularly in the automotive, aerospace, and construction industries.

REFERENCES

1. Shen, Menglu, Lichao Xia, Qiang Feng, Jie Zhang, Jiang Li, and Shaoyun Guo. "Damping characteristics of a multilayered constrained beam using viscoelastic butyl rubber layer with wide temperature range." *Materials Express* 11, no. 3 (2021): 372-380.
2. Banerjee, Ritima, and Suprakas Sinha Ray. "Role of Rheology in Morphology Development and Advanced Processing of Thermoplastic Polymer Materials: A Review." *ACS omega* 8, no. 31 (2023): 27969-28001.
3. Kumar, K. Dinesh, Ganesh C. Basak, and Anil K. Bhowmick. "Adhesion Between Unvulcanized Elastomers: A Critical Review." *Progress in Adhesion and Adhesives* 3 (2018): 185-252.
4. Puskas, Judit E., and Gabor Kaszas. "Polyisobutylene-based thermoplastic elastomers: A review." *Rubber chemistry and technology* 69, no. 3 (1996): 462-475.
5. Kunal, Kumar, Marian Paluch, C. Michael Roland, Judit E. Puskas, Yusheng Chen, and Alexei P. Sokolov. "Polyisobutylene: A most unusual polymer." *Journal of Polymer Science Part B: Polymer Physics* 46, no. 13 (2008): 1390-1399.
6. Nifant'ev, Ilya E., Sofia A. Korchagina, Maria S. Chinova, and Alexander N. Tavtorkin. "Polyisobutylenes with Controlled Molecular Weight and Chain-End Structure: Synthesis and Actual Applications." *Polymers* 15, no. 16 (2023): 3415.
7. Kumar, Rajeev. "Synthesis of Highly Reactive Olefin Functional Polyisobutylene: A Precursor of Oil Additives and Lubricants." PhD diss., University of Massachusetts Lowell, 2014.
8. Xia, Lichao, Chunhai Li, Xiaomeng Zhang, Jianfeng Wang, Hong Wu, and Shaoyun Guo. "Effect of chain length of polyisobutylene oligomers on the molecular motion modes of butyl rubber: Damping property." *Polymer* 141 (2018): 70-78.
9. Rauter, H., V. Matyushin, Y. Alguel, and Th Schalkhammer. "Plenary Lectures Scientific Program S-27." *15th-17th September 2003 Vienna| Austria*: 110.
10. Giller, C. B., and C. M. Roland. "Strength enhancement in miscible blends of butyl rubber and polyisobutylene." *Macromolecules* 46, no. 7 (2013): 2818-2822.
11. Qin, Chao, Qiang Feng, Jie Zhang, Jiang Li, and Shaoyun Guo. "Influence of alternating multilayered design on damping characteristics of butyl rubber composites and a new idea for achieving wide temperature range and high damping performance." *Polymers* 14, no. 24 (2022): 5484.
12. Karamdoust, Solmaz. *Functionalized Polyisobutylene: From Synthesis to Properties and Applications*. The University of Western Ontario (Canada), 2013.
13. Croisier, Emmanuel, Su Liang, Thomas Schweizer, Sandor Balog, Marijana Mionić, Ruben Snellings, Joël Cugnoni, Véronique Michaud, and Holger Frauenrath. "A toolbox of oligopeptide-modified polymers for tailored elastomers." *Nature communications* 5, no. 1 (2014): 4728.
14. Rolón-Garrido, Víctor H., and Manfred H. Wagner. "The damping function in rheology." *Rheologica Acta* 48 (2009): 245-284.
15. Zhang, Jie, Dan Yao, Chao Qin, Ruiqian Wang, Jiang Li, and Shaoyun Guo. "Preparation of microscale multi-layered viscoelastic polymers and analysis of their noise control effects on composite structures." *Composite Structures* 327 (2024): 117702.

Acknowledgment

The authors would like to express their sincere gratitude to Dr. Mohammad Hossein Navazi, Associate Professor of Aerospace Engineering at Sharif University of Technology, for his invaluable assistance in validating the results of the loss factor obtained from the Oberst beam method. All the loss factor results reported in this study were validated by his team, significantly contributing to the credibility and success of this research.