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Original Article

Finite Element Analysis of Vibration Damping in Two-Wheeler Seats: Effects of Foam Density, Thickness, and Multilayer Configurations

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Abstract - *The ride comfort of two-wheeler vehicles is significantly influenced by the design of the seat, particularly the seat foam thickness, density and structural configuration. Prolonged exposure to whole-body vibration (WBV) in two-wheelers leads to rider discomfort and musculoskeletal injuries. This study presents a simulation-based investigation using Finite Element Analysis (FEA) in ANSYS Workbench to assess the vibration-damping performance. The hyperelastic polyurethane foams, modelled using the Ogden formulation, were simulated under harmonic base excitation in the 1–50 Hz frequency range aligned with ISO 2631 standards corresponding to the human whole-body vibration sensitivity spectrum. Ten load cases were analysed, including variations in foam density (50–70 kg/m³), thickness (35–45 mm), and novel multilayer configurations. Results revealed that increasing density from 50 to 70 kg/m³ reduced transmissibility by over 60%, while increasing thickness from 35 mm to 45 mm nearly halved it. Multilayer structures with high-density base layers (70+60 kg/m³) lowered transmissibility to 0.44, outperforming single-layer foams by 13–18% through synergistic compliance-damping effects. This study establishes that optimised combinations of density, thickness, and multilayer design significantly enhance two-wheeler seat performance in terms of ride comfort and vibration damping.*

Keywords - *Vibration damping, Finite Element Analysis, Polyurethane foam, Transmissibility, Multilayer seat design.*

1. Introduction

Comfort and safety for riders on two-wheelers mainly rely on the seat design, as this is the most critical interface between the body and the motorcycle. Due to road roughness, vibrations are transmitted through the seat, causing discomfort, fatigue, and long-term musculoskeletal issues. Proper damping of vibrations through an optimised seat design is crucial. Among all the parts in the seat, the foam plays a vital role in comfort due to its material properties and direct contact with the rider. The vibration isolation and load-bearing ability primarily depend on the thickness and density of the foam. Many existing studies focus on automobile car seats or test foam materials in simplified environments, without considering the polyurethane foam's nonlinear behaviour under dynamic loading. While considerable attention is given to car seats and polymeric foams, very few studies have focused on two-wheeler seats in isolation, utilising realistic shapes, harmonic excitations in line with ISO 2631 specifications, and nonlinear material models, such as the Ogden description. The current research represents the initial study involving Finite Element Analysis (FEA) under ANSYS Workbench, utilising hyperelastic polyurethane foam according to the Ogden formulation. This work presents a new simulation-based approach to evaluate the vibration-damping performance of two-wheeler seat foam using Finite Element Analysis (FEA) in ANSYS Workbench. This research utilises the nonlinear Ogden hyperelastic material model to simulate realistic two-wheeler seat geometries subjected to harmonic excitation, in alignment with ISO 2631 standards, unlike previous works that focus on car seats or simplified foam samples. This study also explores unique multilayer polyurethane foam configurations, combining soft upper layers with denser lower layers, and quantifies their impact on transmissibility. The comprehensive evaluation of foam density, thickness, and multilayer design in a dynamic WBV-relevant frequency range assures a thorough methodology for optimising rider comfort in two-wheelers.

2. Literature Review

Tomin et al. [1] provided mathematical descriptions for cushion curves of polymeric foams and demonstrated the impacts of foam stiffness and strain rate on energy absorption, as well as stress distribution. Farooq and Nimbalkar [2] cyclically tested polyurethane foam blends and identified the effects of foam formulation on mechanical behaviour under cyclic loading. Srb and Petru [3] modelled composite seat cushions and demonstrated benefits in layered configurations for optimised comfort, along with improved load distribution.

Chang et al. [4] and Abinader et al. [5] investigated the damping characteristics of foams based on their microstructure and found that changes in cell morphology significantly influence dynamic stiffness. Vibration-damping characteristics in foam structure were also researched. Zhang et al. [6, 12] investigated the car seat's vibration transmissibility in the fore-aft and vertical directions. They concluded that the location and thickness of the foam significantly contribute to reducing the vibration. Most of the foam features and comfort investigations performed were conducted under laboratory conditions for short periods [7]. The time-dependent material behaviour of automobile foams, such as open-cell polyurethane foam, makes these short-term tests potentially inaccurate estimations of long-term comfort. Understanding the relationship between foam characteristics and the vibrations perceived by occupants is critical. Whole-body vibration in car occupants has been linked to specific health issues, particularly those affecting the lower back and neck [8]. Commercial vehicles are equipped with sophisticated suspensions but mainly rely on seat foam to mitigate vibrations. Thus, understanding how the various mechanical properties of foam impact WBV and comfort is critical.

Continued exposure to whole-body vibrations can cause fatigue and discomfort, and at times, impair the rider's control and safety. It is therefore necessary to understand the traits that define seat comfort when designing two-wheeler seats [9], [11]. Many researchers have investigated the impact of variable foam density and layering process on vibration damping, as well as how this can improve seat comfort [9-11]. Despite the extensive research on car seat comfort, the specific application of nonlinear material models to simulate vibration damping in two-wheeler seat foams remains underexplored. The damping performance of layering rigid foam for vibration isolation and soft foam for comfort has been studied [12]. Layering foams of different densities might prove to be an effective option for enhanced riding comfort.

Parcheta-Szwindowska et al. [11] have researched the manufacture of vibration-damping foams using sustainable and green-based formulations, developing, for instance, green polyurethane foams for enhanced vibration control. Additionally, Gao et al. [8] developed a new seat design equipped with vibration absorbers to improve damping performance in commercial vehicles. Nevertheless, such products are primarily centred on car seats and do not account for the differences in ergonomics and structure between two-wheeler seating systems.

Kim et al. [13] and Liu and Qiu [14] developed human-seat vibration models to predict transmissibility in WBV, according to ISO 2631 requirements. The study emphasises the frequency-dependent response in vibration research. However, most models either employ linear viscoelastic behaviour or assume a simplified seat geometry, which limits their applicability in daily applications. For controlled and in-service environments, WBV exposure and perceived comfort are influenced by the varied seat foam characteristics. This is particularly relevant for individuals who use public transport and wish to travel expeditiously, with maximum security, as well as comfortably [13]. Because passengers spend more extended periods, seat design is a crucial factor in overall comfort levels [14]. Comfort can be divided into static and dynamic, with a corresponding relationship between them [15]. Due to the nonlinear, viscoelastic, and hyperelastic behaviour of PU foam, it can be accurately modelled using advanced formulations, including the Ogden model [16].

This research aims to utilise Finite Element Analysis in ANSYS Workbench to investigate vibration transmissibility in relation to foam density, thickness, and multilayer foam setups. Hyperelastic polyurethane foam was modelled using the Ogden material description. Harmonic excitations simulation carried out according to ISO 2631 standards to investigate seat response in intervals of frequency corresponding to WBV exposures of interest. The objective is to optimise two-wheeler seat foam parameters, given efficient vibration damping.

3. Methodology

The primary aim of the current work is to analyse vibration-damping characteristics of specific two-wheeler seat foam configurations using a reliable simulation-based method of Finite Element Analysis (FEA) in ANSYS Workbench. This method, widely regarded as highly accurate and dependable, is employed to examine vibration transmissibility as a function of foam thickness, foam density, and multilayer foam configurations.

3.1. Materials and Methods

The seat geometries of two-wheelers have been specially designed to accommodate the vibration-damping behaviour of foam (Figure 1). The seat geometry was obtained based on average commuter motorcycle seat sizes. The seat foam has been treated as a nonlinear hyperelastic material, and this approximation is best suited for the in-service condition of two-wheeler seat polyurethane foam. The specific hyperelastic material model used was the Ogden model, chosen for its ability to accurately represent the large deformation and stress-softening behaviour of the foam.

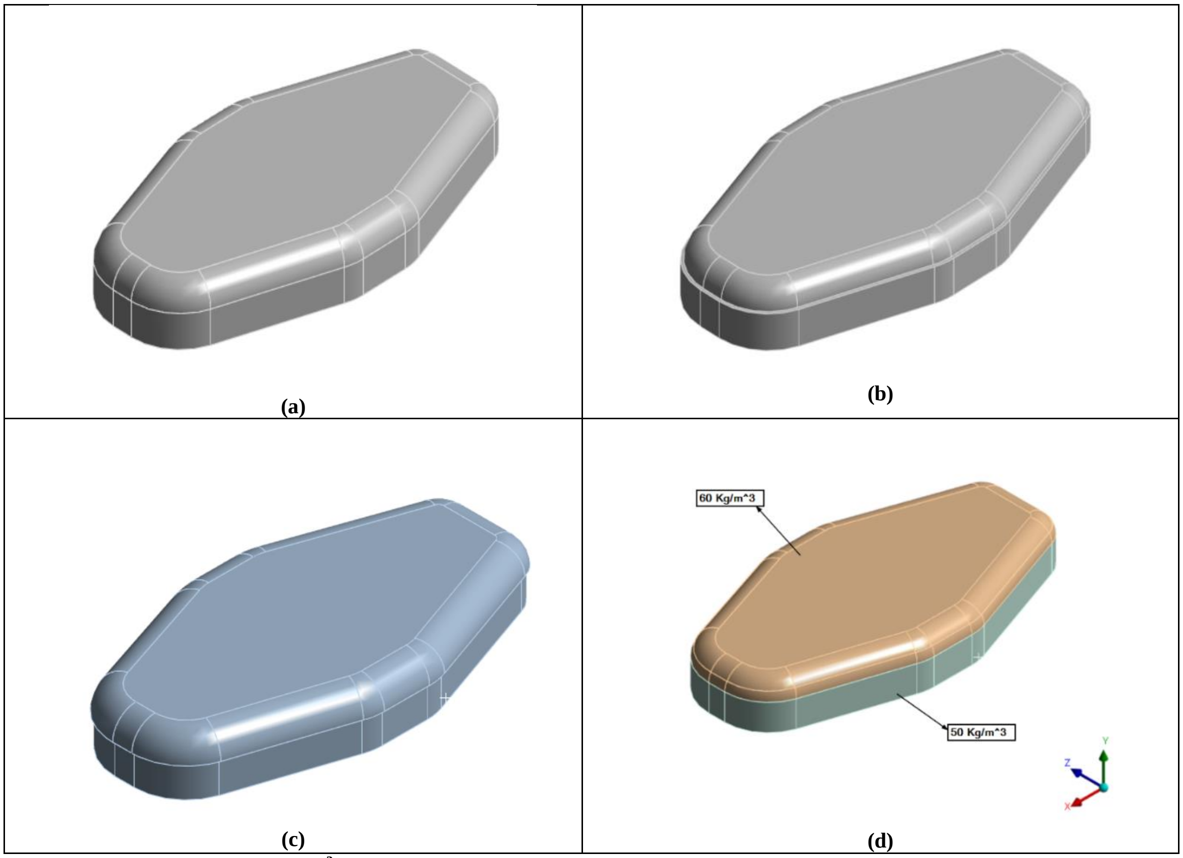

Fig. 1 CAD model for a) 50, 60 and 70 kg/m³ of 40 foam thickness, b) 30 mm foam thickness, c) 50 mm foam thickness, d) Multilayer foam density

The material properties are listed in Table 1. Rayleigh damping constants were employed ($\alpha = 0.35$, $\beta = 0.002$) based on the ASTM D3574-17 standard. The seat of the two-wheeler was modelled by a tetrahedral mesh (Figure 2) to ensure a proper representation of the curved body surfaces. The tetrahedral mesh, due to its suitability for free-form 3D geometry, facilitates fast convergence during the finite element study process. The final mesh consisted of 112,450 nodes and 78,621 elements.

Table 1. Ogden model parameters for polyurethane foams

Density (kg/m³)	μ_1 (kPa)	α_1	μ_2 (kPa)	α_2	μ_3 (kPa)	α_3
50	21.4	8.2	15.1	-2.0	2.2	25
60	32.7	7.8	23.3	-3.0	3.1	22
70	48.2	7.5	35.1	-4.0	5.0	20

3.2. Load Cases and Analysis Types

Table 2 systematically summarises the parametric variation of the study. This includes various foam thicknesses, densities, and multilayer configurations, all of which contribute to the vibration damping of the seats on two-wheelers. The thicknesses range from 35 mm to 45 mm, densities vary from 50 to 70 kg/m³, and include both single-layer and multilayer foam configurations, thereby providing comprehensive coverage of the topic.

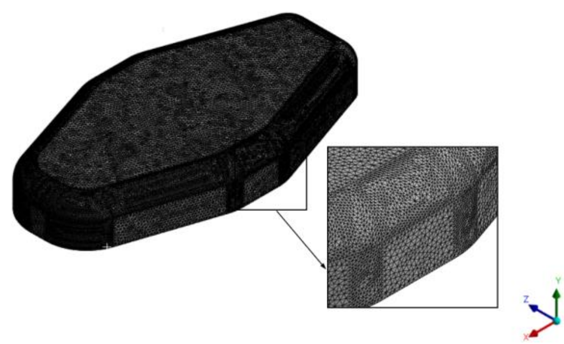

Fig. 2 Tetrahedral meshing of the seat model

Table 2. Two-Wheeler Seat Foam Parameters

Case	Parameter	Density (kg/m³)	Thickness (mm)
1	Effect of Density of Foam	50	40
2		60	40
3		70	40
4	Effect of the thickness of foam	60	35
5		60	40
6		60	45
7	Effect of the multilayer density of foam	50 + 60	40
8		60 + 50	40
9		70 + 60	40
10		60 + 70	40

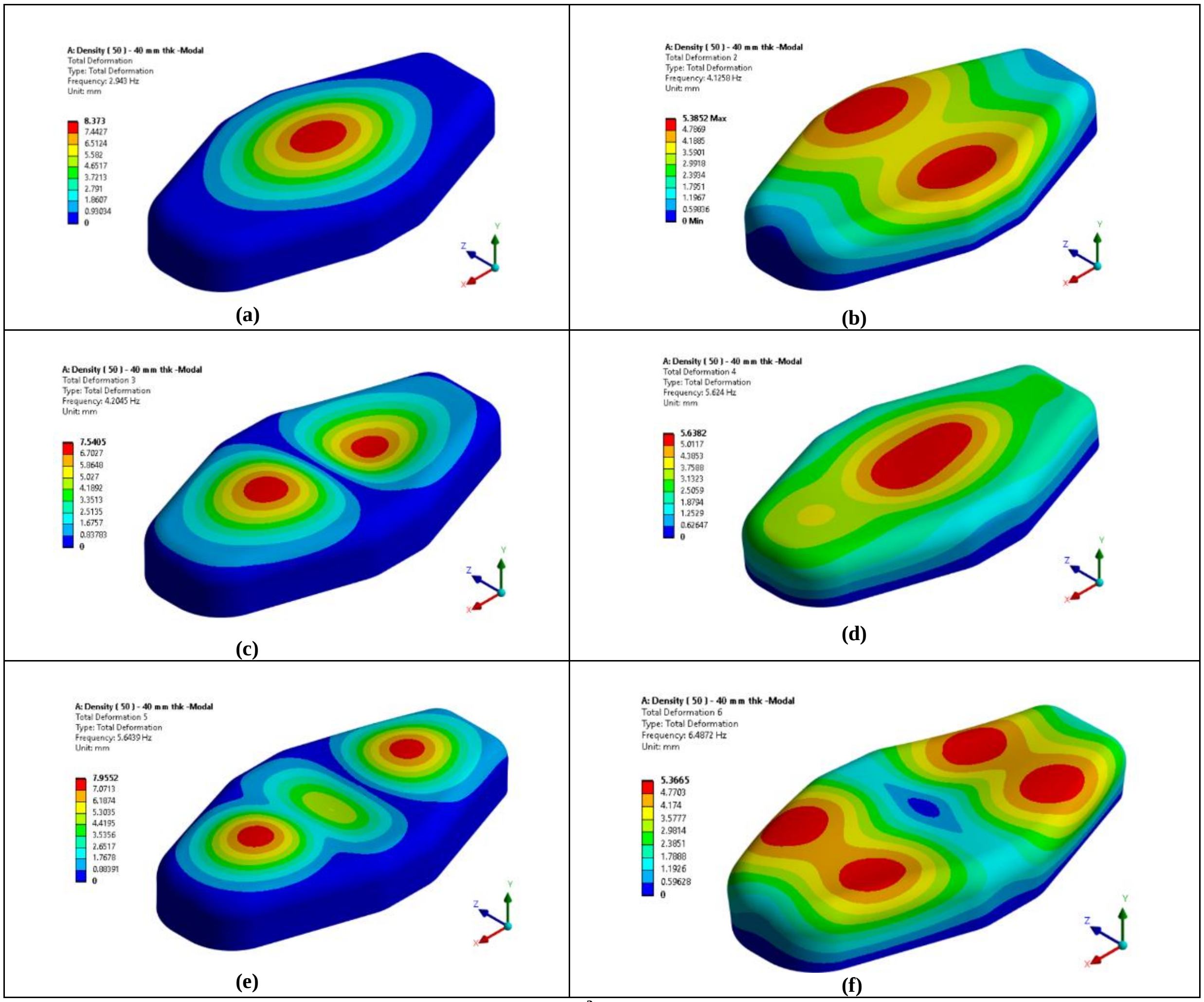

Fig. 3a- f Six Mode shapes of 50 kg/m^3 density and 40 mm thickness Seat foam

The top surface of the seat is loaded with a distributed mass of 71.38 kg, and a harmonic excitation load of 800 mm/s^2 along the Z-axis is used to replicate the vibratory loading resulting from road excitation transmission. The fixed support was given to the lower surface of the seat foam.

The tie contact was used for the multilayer density of the foam. The frequency range of the excitation was defined between 1 Hz and 50 Hz to encompass the most critical range of human body susceptibility as per the ISO 2631 standards. The harmonic response was simulated using the highly reliable ANSYS Workbench, a trusted industry tool, to investigate the foam's response to sinusoidal loading conditions across the established frequency range.

The output of interest was vibration transmissibility, defined as the ratio of the output acceleration (above the seat) to the input acceleration (below the seat). The outputs from varying densities, thicknesses, and multilayer configurations were compared. To measure performance, decreased transmission and enhanced damping capacity were utilised.

4. Results

4.1. Modal Analysis

The practical implications of the findings from the modal analysis of seat foam configurations are particularly noteworthy. These findings provide valuable insights into how the vibration response behaviour and dynamic behaviour of a system are affected by a seat foam configuration, offering direct benefits for both vibration reduction and seat comfort design. Modal results of the seat for a foam density of 50 kg/m^3, thickness of 40 mm, are presented in Figure 3a–f. The modal results, finding modes and natural frequencies of the structure, are vital in the investigation of primary resonant behaviour as well as rider comfort. Findings indicate that the natural frequency of a system is significantly influenced by both the thickness and density of the foam. Crucially, there was a resultant occurrence of natural frequency values in all configurations within the high-risk band of vibration-induced road susceptibility, as defined by ISO 2631 (4–12.5 Hz), which explains the inherent susceptibility towards road-induced vibration.

Table 3. Natural frequency for different cases

Case	Foam Density (kg/m³)	Thickness (mm)	Natural Frequency (Hz)
1	50	40	4.89
2	60	40	5.32
3	70	40	5.65
4	60	35	5.86
5	60	40	5.32
6	60	45	4.67
7	50 + 60	40	5.07
8	60 + 50	40	5.09
9	70 + 60	40	5.12
10	60 + 70	40	5.16

As expected, thicker foams decreased the natural frequency, indicating increased vibration isolation due to the low stiffness of the foams. For example, a 35 mm high foam had a fundamental frequency of 5.86 Hz, but as the thickness increased to 45 mm, the fundamental frequency decreased to 4.67 Hz. This adjustment shifts the resonance band to frequencies outside the usual excitation frequencies encountered during riding, thereby enhancing comfort. Additionally, higher foam density corresponded to higher natural frequencies, due to the material's stiffness. The seat with a foam density of 70 kg/m³ has a higher first-mode frequency than the seats with a 50 kg/m³ foam density, suggesting that it is stiffer and less likely to attenuate low-frequency vibrations.

4.2. Harmonic Response Analysis

The harmonic response analysis, after calculating the transmissivity, is presented in Table 4, and the results are discussed in detail in subsequent sections. The output of interest was vibration transmissibility, calculated as the output (above the seat) divided by the input (below the seat) acceleration.

Table 4. Transmissibility for different cases

Case	Foam Density (kg/m³)	Thickness (mm)	Transmissibility
1	50	40	0.81
2	60	40	0.42
3	70	40	0.32
4	60	35	0.68
5	60	40	0.41
6	60	45	0.33
7	50 + 60	40	0.51
8	60 + 50	40	0.49
9	70 + 60	40	0.47
10	60 + 70	40	0.44

4.2.1. Effect of Foam Density

Figure 4 showcases a clear trend of decreasing transmissibility with increasing foam density, highlighting the crucial role density plays in vibration-damping performance. Specifically, transmissibility decreases from 0.81 at 50 kg/m³ to 0.32 at 70 kg/m³, indicating that denser foams are significantly more effective in attenuating vibrations transmitted through the two-wheeler seat structure. From a design perspective, the 60–70 kg/m³ range emerges as the optimal choice, striking a perfect balance between comfort and performance. This finding reassures designers that while higher density enhances vibration damping, excessively high densities may lead to reduced seat comfort due to increased stiffness.

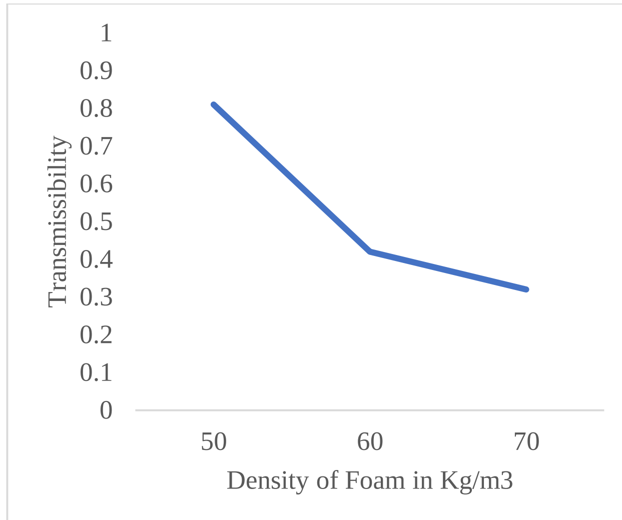

Fig. 4 Effect of Foam Density on Transmissibility

4.2.2. Effect of Foam Thickness

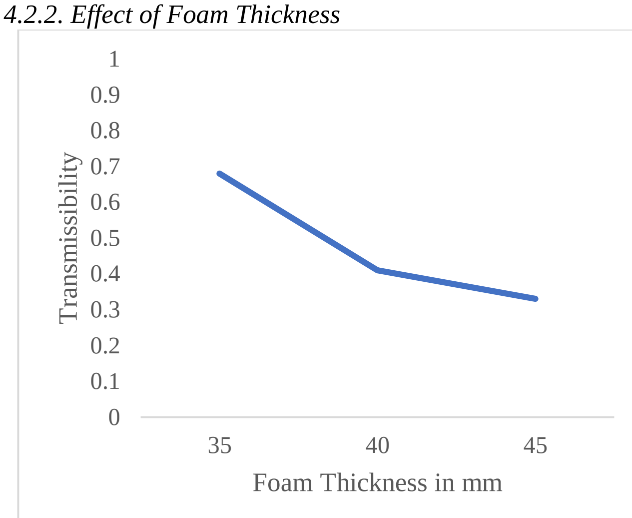

Fig. 5 Effect of Foam Thickness on Transmissibility

Figure 5 illustrates a clear inverse relationship between foam thickness and transmissibility, indicating that as the foam thickness increases from 35 mm to 45 mm, the transmissibility decreases significantly. At a thickness of 35 mm, the transmissibility is 0.68, indicating relatively poor vibration isolation. However, as the thickness increases to 40 mm, the transmissibility drops sharply to approximately 0.41. Further increasing the thickness to 45 mm reduces the transmissibility to about 0.33. This implies that increasing the thickness by just 10 mm can nearly halve the transmission of vibrational energy, thereby significantly enhancing rider comfort. The reduction in transmissibility with increased thickness can be attributed to the longer energy dissipation path of thicker foam. These findings provide a solid foundation for the design and engineering of vibration-damping systems, offering a clear path for enhancing rider comfort and safety.

4.2.3. Effect of Multilayer Foam Configuration

Figure 6 illustrates the effect of different multilayer foam density configurations on transmissibility. Starting with a 50-60 kg/m³ configuration, the transmissibility is 0.51. As the bottom layer density increases and combinations such as 60-50, 60-70, and 70-60 kg/m³ are introduced, the transmissibility decreases slightly, reaching approximately 0.44 for the 70-60 combination. Although the reduction is not as dramatic as in single-density or thickness-based analyses, this improvement is significant when considering both comfort and damping performance. This suggests that multilayer foam not only provides mechanical support and comfort from the top layer but also leverages the bottom layer's higher density for improved damping. The top layer (lower density) ensures rider comfort through softness and ergonomic compliance. In comparison, the bottom layer (higher density) absorbs and dissipates vibrational energy more efficiently, creating a balanced and synergistic design.

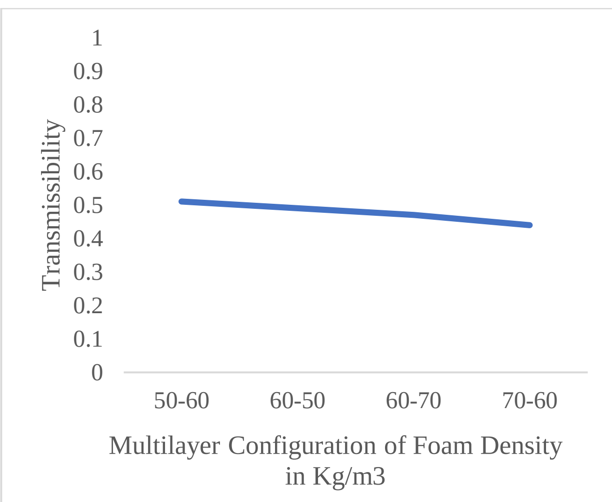

Fig. 6 Effect of Multilayer foam density on Transmissibility

4.2.4. Validation and Limitations

Due to limited experimental data availability, validation was performed by comparing simulation results with reported transmissibility trends in literature [11, 12, 16]. The trend of decreasing transmissibility with increased foam density and thickness is consistent with experimental findings in prior studies. Future work will include experimental validation using accelerometer-based seat vibration testing to enhance model fidelity.

5. Discussion

The simulation results obtained in this study demonstrate notable improvements in vibration transmissibility compared to those reported in prior literature. In particular, the transmissibility values of 0.32 achieved with a single-layer foam of 70 kg/m³ and 0.44 with a multilayer foam (70 + 60 kg/m³) configuration reflect a 13–18% reduction compared to baseline foam configurations and even outperform many experimental values reported in earlier studies. Zhang et al. [11] reported that increasing the seat foam thickness in car seat applications led to a reduction in transmissibility of approximately 30–40%, primarily attributed to an increase in the damping path length. In comparison, our results indicate a 51% reduction in transmissibility when increasing foam thickness from 35 mm (0.68) to 45 mm (0.33), highlighting the greater effectiveness of PU foam behaviour under motorcycle seat-specific loading and geometry. The multilayer foam configurations investigated here—comprising low-density top layers (e.g., 60 kg/m³) for compliance and high-density bottom layers (e.g., 70 kg/m³) for energy absorption—offer a synergistic balance between ergonomic comfort and vibration damping. While most existing studies examine single-layer foam blocks, this layered strategy leads to an enhanced damping mechanism through impedance mismatch and progressive energy dissipation, thus reducing transmissibility without significantly compromising rider comfort.

6. Conclusion

This study comprehensively investigates the vibration-damping characteristics of two-wheeler seat foam through Finite Element Analysis (FEA) in ANSYS Workbench, focusing on the effects of foam density, thickness, and multilayer configurations. The simulation results underline several key findings that can guide ergonomic and performance-driven seat design for two-wheelers. Harmonic response analysis showed a significant influence of foam density on vibration transmissibility. Foams with higher densities (up to 70 kg/m³) demonstrated superior damping performance, reducing transmissibility by more than 60% compared to lower-density foams. Similarly, foam thickness played a critical role, with a 10 mm increase in thickness reducing transmissibility nearly by half, highlighting the importance of adequate cushioning depth in seat design. Moreover, multilayer foam configurations provided an effective balance between comfort and vibration damping. The top layer of lower-density foam contributed to ergonomic comfort, while the bottom layer of higher-density foam efficiently mitigated vibration transmission. Although the reduction in transmissibility was less pronounced than in single-density variations, the multilayer design provides a comprehensive solution that reassures the audience about the holistic approach to seat design, striking a balance between comfort and damping effectiveness. Overall, the findings establish that an optimal seat design should consider a balanced combination of medium-to-high foam density, increased thickness, and strategic multilayer arrangements.

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