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Original Article

Experimental Study on the Impact of Seat Foam Thickness, Density, and Multilayer Configurations on Vibration Damping in Two-Wheelers

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Abstract - *The seat foam of a two-wheeler plays a vital role in overall comfort. Vibration transmission from the seat to the rider is an important factor that affects rider comfort and fatigue, and is largely dependent on the seat foam configuration. An experiment was conducted to determine the influence of seat foam thickness, its density, and multilayer arrangement on vibration damping. An ADXL345 three-axis accelerometer was used to measure seat vibration. For real-time data from the city road, the vehicle was running on a fixed path at 20 km/h and recorded both engine and road-excited vibration. The experiments showed that as the foam thickness increased from 30 mm to 50 mm, seat vibration acceleration decreased significantly. Moreover, increasing the foam density from 50 kg/m³ to 70 kg/m³ resulted in higher seat vibration due to increased stiffness. Furthermore, no significant change in vibration through the utilisation of multilayer density configuration (such as 50-60 kg/m³ & 60-50 kg/m³) compared to single-layer foams with the same thickness. These results clearly indicate the need to optimise seat foam parameters to bring comfort in vehicle seats.*

Keywords - *Foam Density, Foam Thickness, Multilayer configuration, Seat Foam, Vibration Damping.*

1. Introduction

Two-wheeled vehicles are widely used for day-to-day transportation, particularly in urban and semi-urban areas, due to their cost-effectiveness and fuel efficiency. Nevertheless, the rider's comfort is a significant concern that must be addressed when considering the use of two-wheeled vehicles for extended periods. One of the major concerns regarding the rider's comfort is the transfer of vibration from the vehicle to the rider through the seat. Such vibration results from engine vibration and road irregularities, causing discomfort to the rider and leading to health problems during long hours of driving.

The vehicle's seat is a major factor to consider when addressing vibration transfer from the vehicle to the rider. In general, polyurethane foam is a major material for motorcycle seats due to its superior mechanical properties. In addition, polyurethane foam is cost-effective and easy to process. The vibration-damping characteristics of polyurethane foam depend on several parameters, such as thickness, density, and structural configuration.

Several studies have been conducted to analyse the characteristics of seat vibrations. The existing research mainly focuses on controlled environments or four-wheeled vehicles, and there is a need to analyse the performance of the foams concerning two-wheeled vehicles. Additionally, the performance of foams under both engine- and road-induced vibrations in two-wheeled vehicles is not sufficiently examined in the current literature.

The present study aims to conduct an experimental analysis of foam performance in the context of two-wheeled vehicles. The performance of foams in two-wheeled vehicles is analysed with respect to foam thickness, density, and multilayered configurations. Unlike previous studies conducted under laboratory or simulation conditions, this study provides real-road experimental validation for two-wheeler seat vibration. Thus, the novelty of this work lies in its real-road experimental validation, integrated parameter evaluation, and practical design-oriented conclusions for two-wheeler seat optimisation.

2. Literature Review

In the context of seat vibration damping, the existing literature has examined the effects of foam properties, including thickness, density, and material composition. The literature clearly shows that as the thickness of the foam material increases, damping performance improves. In this regard, Luo [1] reported that as the foam thickness increases, damping performance improves by reducing the vibration transmissibility peak. Zhang et al. [2] also reported similar observations and showed that as the foam thickness increases, the dynamic stiffness decreases, thereby improving the material's damping performance.

In terms of material composition or density, the literature clearly indicates that as material density increases, damping performance decreases due to increased material stiffness. Similar observations were reported by Hassan et al. [3], who showed that as the material density increases, damping performance decreases due to increased material stiffness. Regarding the composition or number of layers of the damping material, the literature clearly indicates that as the number of layers increases, damping performance improves. Mali and Bhosale, through finite element analysis of the subject, reported similar observations and illustrated that, as the number of layers increases, transmissibility decreases substantially.

Regarding advanced damping materials, various studies have been conducted to improve the damping performance of seat vibration-damping materials. For instance, Trencio et al. [4] reported similar observations. They demonstrated that when a Sorbothane-based damping material is used for seat vibration damping, damping performance is substantially improved due to its viscoelastic properties. In addition to the commonly used damping material, such as polyurethane foam, various other damping materials, including viscoelastic polymers and damping material-based damping substances, have been explored for seat vibration damping [5]. For instance, Dykstra et al. [6], using metamaterial-based damping substances for vibration damping of a seat, reported similar observations and illustrated that, as metamaterial-based damping substances are used for vibration isolation, their performance improves.

From a human-centred perspective, studies on WBV have focused on seat design, emphasising its importance in controlling WBV and improving human comfort [7]. Pan-Zagorski et al. [8] have pointed out that foam properties have significant effects on WBV under both laboratory and field conditions. Additionally, Chwalik-Pilszyk [9] has validated the use of polyurethane foam to control WBV for passengers, and Desai et al. [10, 11] have used biomechanical models to evaluate ride comfort under dynamic conditions. In addition to vibration, seat material properties are important for product durability, as van Oosten [12] has noted that ageing and degradation of polyurethane foam significantly affect its cushioning properties.

Although significant research has been conducted on WBV, some gaps remain in the current body of knowledge, particularly regarding its application to two-wheeler vehicles. Most research has been conducted under laboratory conditions, and few studies have focused on four-wheeler seating systems, whereas the actual conditions for two-wheeler vehicles may differ significantly. In addition, most studies have focused on individual parameters, whereas little consideration has been given to their interactions, particularly in multi-layer configurations.

Recent studies have provided insight into the intrinsic properties of polyurethane foam, with particular attention to density, thickness, and microstructure. It has been established that polyurethane foams have an exceptional ability to dampen vibrations, provide cushioning, and absorb energy due to their unique structure and viscoelastic nature [13]. Recent studies on vibroacoustics have shown that dynamic stiffness and damping coefficient are crucial factors that determine vibration isolation properties in polyurethane foam [14].

In addition, recent studies have shown that foam density significantly affects the material's stiffness, compressibility, and energy absorption capacity. High-density foam is stiffer and can withstand loads better than low-density foam, but, on the downside, it has lower damping efficiency due to its lack of deformation [15]. Similarly, foam thickness also plays an important role in vibration reduction; greater thickness results in enhanced damping efficiency through greater energy dissipation and reduced transmissibility across a wide range of frequencies [16].

Furthermore, recent advancements in polyurethane foam technology have emphasised the need to improve damping efficiency through microstructural optimisation. Recent polyurethane foams have demonstrated higher damping coefficients and wide operating temperature ranges [17, 18].

Thus, the existing literature confirms that seat foam material properties play an important role during vibration excitations. Nonetheless, these findings are primarily limited to passenger vehicle seating systems or controlled laboratory conditions. An experimental study of two-wheeler seats under real-riding conditions remains scarce, particularly one evaluating the combined effects of foam thickness, density, and multilayer configurations. Consequently, there is a need for experimental studies to investigate seat vibration behaviour under actual operating conditions while accounting for multiple foam properties. This limitation motivates the present experimental study. This study aims to fill this research gap by conducting an experimental study on a two-wheeler seat, investigating the effects of foam thickness, density, and multi-layer configurations to provide useful insights for improving comfort by vibration damping.

3. Materials and Methods

The methodology used in this analysis consists of modifying a two-wheeler seat design, integrating a vibrationmeasuring sensor, conducting controlled experimentation, and analysing the data. This analysis evaluated vibration damping by mounting the sensor on the vehicle seat at the rider's location to ensure consistent readings, as shown in Figure 1. An ADXL345 3-axis accelerometer connected to an Arduino Uno microcontroller, as shown in Figure 2, acquires vibration data and transmits it to a laptop. The first step was to evaluate the seat without any foam, as shown in Figure 3a, to obtain a baseline vibration level. Subsequently, foam layers of varying thicknesses (30 mm, 40 mm, and 50 mm), as shown in Figure 3 (b-d), densities (50, 60, and 70 kg/m³) as shown in Figure 3 (c) and 3 (e) and multilayer configurations (50+60 kg/m³ and 60+50 kg/m³) as shown in Figure 3 (f) were tested. The accelerometer captured acceleration data along three axes, processed using Arduino via I2C communication, and recorded vibrations in units of m/s². As most vibrations are transferred in the z-axis, only those vibrations are considered for analysis. The readings were taken while the two-wheeler was moving at 20 km/h to determine how different foam properties affect vibration output. This method helps establish the relationship between the foam's properties and its vibration-damping effectiveness.

The present study focuses on time-domain analysis of vibration based on Root Mean Square (RMS) acceleration values obtained from real-road experiments. Although vibration comfort is frequency-dependent, no frequency-domain analysis was performed due to hardware limitations. However, the measured acceleration values provide a reliable comparative assessment of vibration-damping performance across different foam configurations under identical riding conditions.

Fig. 1 Experimental set up

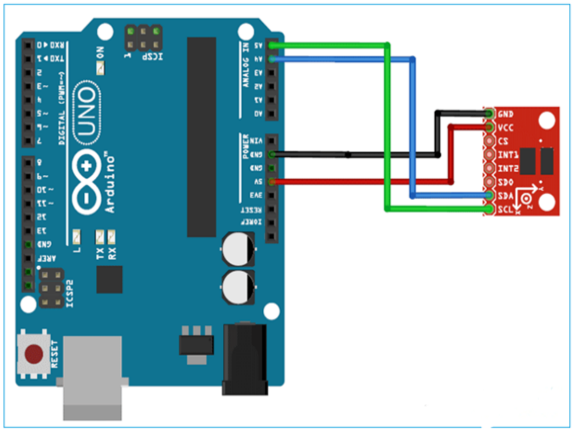
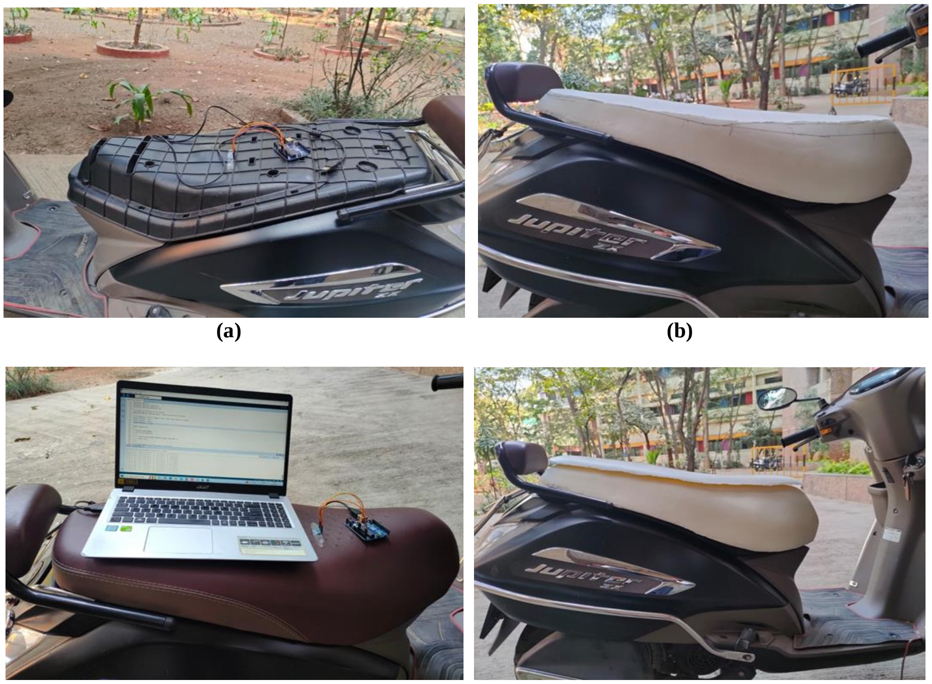


Fig. 2 ADXL345 accelerometer interface with arduino



(a)

(b)

(c)

(d)

(e) (f)

Fig. 3 Different foam configurations (a) Seat with no foam, (b) 30 mm thickness and 60 kg/m³ density foam seat, (c) 40 mm thickness and 60 kg/m³ density foam seat, (d) 50 mm thickness foam seat 60 kg/m³ density foam seat, (e) 40 mm thickness and 50 kg/m³ density foam seat and (f) Multilayer foam density (50-60 kg/m³) with an overall 40 mm-thick foam seat.

The tests were conducted under real riding conditions to ensure accurate vibration readings. For each foam configuration, multiple experimental runs were performed under identical riding conditions to ensure data repeatability. The variation between repeated measurements was minimal, indicating consistent sensor performance and stable riding conditions. Therefore, RMS acceleration values were used for comparative analysis. The results obtained help in optimising seat parameters for improved rider comfort.

4. Results

Vibration analysis was conducted on a two-wheeler seat with various foam configurations and compared to a seat without foam. The results show how different foam configurations affect the seat's vibration damping.

4.1. Effect of Seat Foam with Different Thicknesses on Vibration Damping

The impact of seat foam with different thicknesses (30 mm, 40 mm, and 50 mm) on a two-wheeler seat was analysed and compared with a seat without foam using a vibration test.

The results are shown in Figure 4 and provide details on how increasing foam thickness affects vibration damping. This Figure shows that as the foam thickness increases, the acceleration decreases.

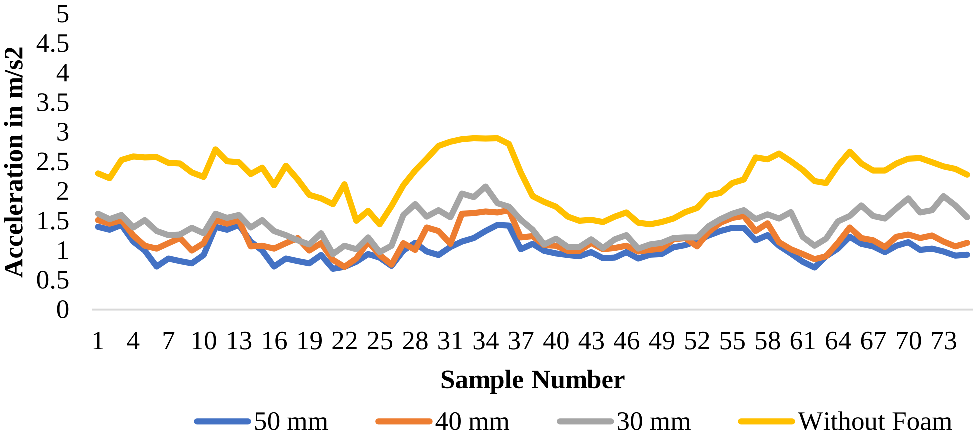


Fig. 4 Effect of Foam Thickness on Vibration Damping

To show the effect of foam thickness variation on vibration damping, the RMS acceleration was calculated and is presented in Table 1. The seat without foam has the highest vibration level, indicating it provides little comfort and is inefficient at absorbing vibration, so PU foam is used.

The results show that increasing PU foam thickness increases vibration damping and enhances rider comfort. The greatest vibration reduction was observed at a foam thickness of 50 mm. Even though a PU foam seat with a 50mm foam thickness is optimal for vibration reduction, other factors, such as cost and ergonomics, need to be considered.

Table 1. RMS acceleration at different foam thicknesses

Foam Thickness (mm)	**RMS Acceleration (m/s^2)**	**% Reduction (Compared to Without Foam)**
Without Foam	2.2061	—
30 mm	1.4272	35.33% ↓
40 mm	1.1868	46.20% ↓
50 mm	1.0348	53.10% ↓

The damping values increase with increasing foam thickness up to 40 mm, then slow down at 50 mm. Thickness is 40 mm, making it a cost-efficient option. The maximum damping value, i.e., 53.10%, occurs at a foam thickness of 50 mm; however, the rate of increase slows (6.9% from 40 mm to 50 mm). This suggests 40 mm foam may be the optimal balance between performance and material efficiency.

4.2. Effect of Densities on Vibration Damping

From Figure 5, it is observed that varying the foam density can reduce vibration and improve overall comfort under the vehicle's moving condition. The result highlights the importance of understanding vibration and foam dynamics to improve seat comfort.

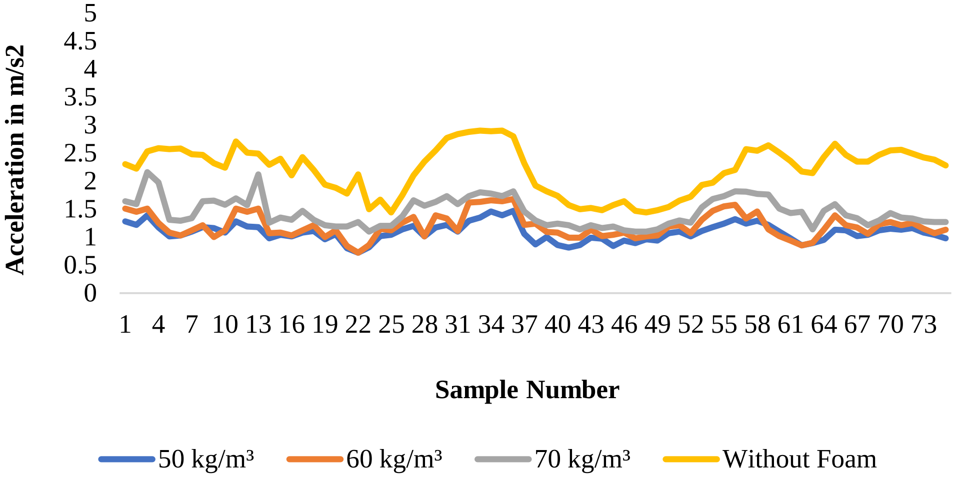


Fig. 5 Effect of Foam Densities on Vibration Damping

With the increase in foam density from 50 kg/m^3 to 70 kg/m^3, the RMS acceleration increases, as shown in Table 2. This indicates that higher-density foam contributes to more vibration. Lower-density foams have more air pockets and flexible cell structures, which allow vibration to dissipate through elastic deformation.

Higher-density foams have fewer air pockets and more solid material, so they transmit more vibration rather than absorbing it. The foam with a density of 50 kg/m^3 provides the maximum vibration reduction of 49.08% compared to no foam. With an increased density from 50 kg/m^3 to 70 kg/m^3, vibration levels increase. This suggests that higher-density foams become too stiff, reducing their ability to dissipate energy effectively.

Table 2. RMS acceleration at different foam densities

Foam Density (kg/m^3)	**RMS acceleration (m/s^2)**	**% Reduction (Compared to Without Foam)**
Without Foam	2.2061	—
70	1.4434	34.57% ↓
60	1.1993	45.63% ↓
50	1.0828	49.08% ↓

4.3. Effect of Multilayer Density of Foam

In a multilayer density configuration for seat vibration damping, both foam layer density configurations appear to have a similar impact on vibration damping, as shown in Figure 5. The actual arrangement of layers in a multilayer configuration, for example, having a hard foam layer followed by a medium foam layer, versus having the medium foam layer on top of the hard layer, has the same effect on the vibration-damping capabilities of the seat.

Table 3. RMS acceleration at Multilayer Foam configuration

Foam Configuration	**RMS acceleration (m/s^2)**	**% Reduction (Compared to Without Foam)**
Without Foam	2.206	—
50 + 60 kg/m^3	1.109	49.72% ↓
60 + 50 kg/m^3	1.095	50.36% ↓

Analysis of the results shows that the vibration-reducing characteristics of the multilayer foams (50 + 60 kg/m^3 and 60 + 50 kg/m^3) are almost equal.

From Table 3, it is concluded that multilayer foams demonstrate slightly improved vibration reduction compared to some single-layer configurations; however, the difference between the two-layer arrangement and the single-layer configuration is not significant. Damping behaviour is more dependent on material properties and total thickness rather than layering with different densities.

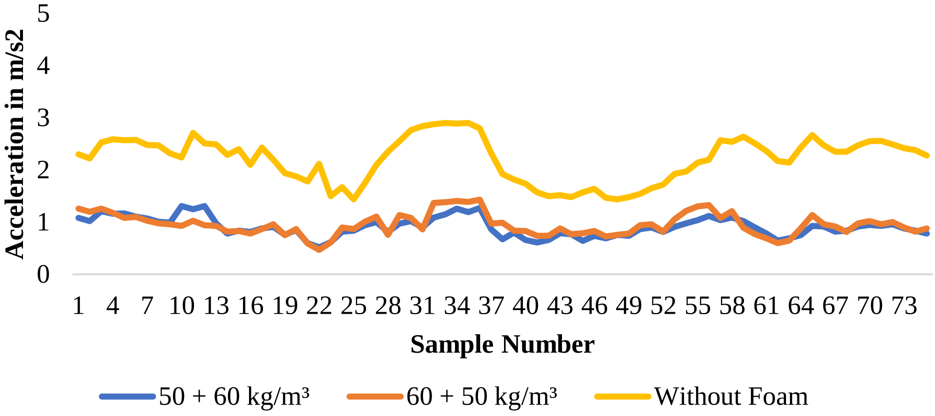


Fig. 6 Effect of Multilayer Foam configuration on Vibration Damping

5. Discussion

The findings of the current study align well with the trends identified in the literature. In the past, it has been established that the thickness of the foam material reduces the transmissibility of the vibrations [1, 2]. The current study also observed a similar trend: increasing thickness from 30 mm to 50 mm reduces vibration acceleration. This can be attributed to the material's increased deformation capacity.

The increased vibration levels observed for the higher-density materials also align with the literature, which reports that higher-density materials exhibit greater stiffness and reduced damping [3]. In contrast, lower-density materials exhibit greater flexibility, thereby providing improved damping capacity. Regarding multilayer materials, the current study identified negligible improvements, consistent with trends reported in the literature using computational methods.

Unlike the trends identified in the literature, the current study accounted for the effects of real-world roads, including the combined effects of the engine and road vibrations. This provides a more accurate evaluation, especially of the seats, as emphasised in studies on WBV [7, 8]. The results of the current study indicate that material thickness and density are important, while the effects of multilayer materials are similar.

5.1. Comparison with Advanced Materials

Advanced materials such as viscoelastic gels and metamaterials offer superior damping but are costly and complex, and their effectiveness in real-world two-wheelers remains to be further investigated [5, 6]. Polyurethane foam remains a practical solution due to cost-effectiveness and manufacturability.

5.2. Frequency Domain (FFT/PSD) Analysis

The focus of the existing analysis has been on the application of time-domain acceleration; however, future studies may consider frequency-domain analysis tools such as the Fast Fourier Transform (FFT) and Power Spectral Density (PSD), which are likely to provide a better understanding of the characteristics of vibration and how it relates to human sensitivity, as per ISO 2631-1 standards.

5.3. Human Comfort Perspective

Human perception of vibration varies with frequency and amplitude. Future studies may adopt a human-centred approach to achieve a more realistic assessment of comfort. Furthermore, the analysis will consider different speeds, road conditions, and the rider's mass. Also, the application of statistical tools, such as standard deviation, should be considered to obtain more reliable results.

6. Conclusion

Investigating different foam characteristics, such as thickness, density, and layer configurations, provides valuable insights into how vibration damping can be improved in automotive seats. Increasing the foam thickness from 30 mm to 50 mm reduces seat vibration acceleration. However, increasing foam density from 50 kg/m³ to 70 kg/m³ increases seat vibration acceleration.

In other words, foam density adversely affects vibration-damping performance. Furthermore, layering configurations such as 50-60 kg/m³ and 60-50 kg/m³ both have a similar impact on vibration-damping performance. In summary, the foam thickness and density are primary determinants of vibration-damping performance, whereas layering configuration is secondary.

In future studies, the exploration of different vibration-damping materials, such as gel or memory foam, can also be considered to improve the performance of the existing foam used in motorcycle seats, potentially resulting in a more effective seat model.

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