Materials Today: Proceedings 62 (2022) 2291–2296

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Structural and dynamic analysis of automotive quarter car model suspension system for different materials

M. Muzakkir Ahamed *, L. Natrayan

Department of Mechanical Engineering, Saveetha School of Engineering, SIMATS, Chennai 600124, Tamil Nadu, India

ARTICLE INFO

Article history:
Available online 2 May 2022

Keywords:
Vehicle comfort
Dynamic
NVH
Random
Suspension

ABSTRACT

The suspension system is a group of mechanical components that links the wheels to the frame or chassis. Suspension systems have received a significant deal of engineering attention as part of an ongoing effort to improve vehicle ride and handling as well as passenger comfort and safety. As the noise, vibration and harshness (NVH) issues are at the forefront of the customers perspective, the vehicle comfort and stability have been considered. In the passenger four-wheelers, shock absorption and vibration due to random excitation are prevalent. The suspension effects play a major role in absorbing the shocks. Hence, this work attempts to model a car suspension and analyzed the dynamic behaviour due to external excitation forces. Among the investigated materials, the epoxy based composites ended-up with the larger deformations and higher stresses compared to the aluminium and steel.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Design, Manufacturing and Materials Engineering.

1. Introduction

The vehicle structure is the skeleton supports the engine and the body parts that stabilize the vehicle vibration and force acting on it. The objective of the structure analysis is to increase the vehicle comfort by providing proper suspension system like the springs and the engine mount [1]. Here the boundary condition is the arresting of the frame with respect to the degree of freedom. The vehicle model is modeled [2] such that the weight of the material is less and due to that the magnitude of the vibration caused should not be increased [3]. Here the vehicle suspension frame work is considered as a quarter models for the analysis [4]. The aim of these studies is to look at a quarter vehicle with the goal of dissecting comfort while taking into account the compliances in safety and The model has a suspension top mount and a solid setup [5].

Models of differing multifaceted nature seeing just direct unique components to frameworks including nonlinear components, have been created to foresee, explicitly, vehicle dealing with and, somewhat, ride comfort. For instance, safeguards have been displayed to speak to hydro mechanical conduct; Because of the model's complexity, simple integration into car element systems is not feasible [6]. It is difficult to conduct parametric studies and interpret the outcomes [7]. In latent improved models, safeguard is treated damper, most straightforward being a direct model. Frequently, components interfacing the safeguards to the suspension framework and the impacts of different commotion and vibration structures are overlooked [8].

To build a simple automobile prototype, the quarter car model is examined with two degrees of freedom to assess the discomfort due to vibration and to increase the suspension characteristics. Here the model is made in such a way that the stiffness of the types and the wheel is considered to be the mass with two degrees of freedom. It is represented by a spring and damper icon, similar to the Kelvin-Voigt model, also known as the ordinary model. In addition, the mass of the vehicle body [9]. In analysis of the simplest classical of the quarter model suspension arrangement in industries is considered as the one which is exposed to the impulsive forces and absorbed as the dynamic response output. Hence as we know the suspension system is a combination of the spring and damper arrangement in which the negative force transmission is eliminated by arranging the spring stiffness to be in series and the mathematical equation is obtained [10]. In this way the noise, vibration and harshness in the vehicle is analyzed for the frequency ranging from the lower frequency to higher frequency to achieve the vehicle comfort.

* Corresponding author.
E-mail address: muzakkir360@gmail.com (M. Muzakkir Ahamed).

https://doi.org/10.1016/j.matpr.2022.04.072
2214-7853/
Selection and peer-review under responsibility of the scientific committee of the International Conference on Design, Manufacturing and Materials Engineering.

In Kelvin-voigt model the shock absorber is not considered the effect for the compliance and the overall stiffness due to the series arrangement as a representation is needed to be used as a Maxwell model or visco-elastic element. In this way the pressure inside the shock absorber is relieve using the damping force.

2. Literature review and problem statement

Viswanath.K.Allamraju [11] considered a mathematical apparatus for displaying and breaking down a two-level opportunity quarter vehicle model suspension framework modular investigation of quarter vehicle model suspension framework by considering the undamped and damped factors. The modular and vertical movements portraying the suspension framework were settled hypothetically for damping cases.

Thite [12] conducted study to create and test an instantaneous car zone suspension model that integrates the influence of series stiffness in analyses the reaction at higher frequencies; approaching Maxwell's models provides not enable clear estimation of execution constraints. Investigating the motion conditions are controlled to compute the feasible firmness and damping values of the structure. The country-area model is masterminded in a new manner of structure that facilitates in locating out the eigenvalues, a unique commitment. The investigation reveals that suspension damping and collection firmness have an effect on the consistent frequencies and decreasing vibration reaction zones. Expansion within the suspension damping constant outside perfect traits reduced the modular damping and incremented the regular frequencies. It is clear that a preliminary creation of the frequency evaluation may be done the usage of the advancement of the generation in developing the suspension system and the damping coefficient.

Hegazy and Sharaf [13] had carried out a specific hypothetical test exam for ride solace assessment at various automobile speeds. 1 / 4 automotive model with degrees of potential has been designed with the give up goal of trip solace evaluation. The similar qualities of suspension solidness and guard properties are established and combined to reenactment for reasonable exam. The sprung mass, upsprung mass, suspension framework, and tyre are all included in an on-hand region vehicle inspection rig for single loose front suspension. An offbeat wheel that addresses the road profiles is used to pressure an excitation of sinusoidal street profiles with consistent sufficiency. Because road excitation is predicted, recorded, and handled, the trial aftereffects of the sprung mass and upsprung mass speed rise. At varied rates, the possible outcomes with test results have been accepted. When using the identical suspension solidness and damping coefficient as information bounds to the quarter vehicle model addressing the free front suspension, a terrific arrangement was obtained.

Current automobile suspension frameworks make use of inactive segments solely using spring and damping coefficients with constant fees. Vehicle suspensions frameworks are typically evaluated by means of their capability to offer super avenue managing and increase visitor solace. Aloof suspensions provide a change off between those clashing models. Dynamic suspension represents the potential to decrease the conventional plan as a alternate-off amongst looking after and solace by using straightforwardly controlling the suspensions electricity actuators. In this examination, the Linear Quadratic Control (LQR) procedure changed into executed to the dynamic suspension's framework for a quarter vehicle version. Examination amongst inactive and dynamic suspensions frameworks is finished by means of utilizing numerous road profiles. The regulator's display is contrasted as are the LQR regulator and the inactive suspension framework [14]. Pankaj Sharma et al., the aim of confining the vibrations created due to avenue aggravations from being moved to the motive force. In this study, a 1 / 4 vehicles version with two DOF is envisioned. The influence of a challenge as step painting is broken down for overrun and settle season of sprung and unsprung mass. MATLAB application changed into created for the examination using the nation area version. The software created right here may be utilized for and vehicles quarter vehicle models with 2DOF for research, with the intention to be valuable in placing apart cash needed for check apparatuses and circuits [15].

Sathishkumar et al. [16] This paper examines the numerical demonstrating and undertaking research of two-level of opportunity quarter automobile model. The state-space numerical model is inferred utilizing Newton's 2d law of movement and loose body chart idea. The automobile body alongside the wheel framework is displayed as a two-degree possibility area car version. The presentation of the framework might be managed by way of PC exercise utilizing MATLAB/SIMULINK. Aloof, semi-dynamic and dynamic suspensions frameworks are associated in a solitary circle and attempted underneath strengthen and single knock input. Mitra et al. [17] Suspension framework configuration is tough for the automobile originators thinking about extraordinary manipulate obstacles, complicated desires, and unsettling stochastic affects. It isn't always smooth for automobiles to preserve up with an unique expectation of ride solace, automobiles taking care of below every using condition. This paper aimed to foster a MATLAB/SIMULINK model of a complete automobile to investigate the journey solace and car looking after. Just as the unique research of numerical demonstrating with step by step association of the kingdom-space network is to be created and approval of Simulink version with a logical association of the country-space framework is to be completed extravagantly in this paper.

V. M. Barethiye et al. [18] quarter vehicle model broke down the execution of vehicle qualities to contemplate the impact of safeguard, based on straight and nonlinear damping attributes. Polynomial damping characteristics were explored to handle the nonlinear element of damping attributes, rather than standing direct and piecewise straight. The safeguard's natural and nonlinear qualities were combined in a two-level opportunity quarter vehicle suspension structure. Adams observes climate and MATLAB/Simulink are used for presenting and reenactment. To energize the quarter vehicle, suspension models, a knock street profile was used. The polynomial safeguard model was approved utilizing trial information taken from setup writing. Reproduction was attempted to consider the powerful exhibition regarding the increase of the sprung mass speed, body relocation, suspension avoidance, and unsprung mass speed. Test hysteresis attributes information, taken from set up writing, was likewise demonstrated in Adams see climate, and the recreated results were utilized for approval reasons. Suresh and Joshib's [19] study portrays an experimental investigation of two degree of freedom (DOF) sector-car detachable suspension framework and water-pushed dynamic suspension framework (QC-H-ASS) for trip comfort. The sprung mass, usprung mass, suspension spring and damper, and tired spring are all part of the uninvolved suspension structure, which replicates a quarter vehicle suspension. A strain-driven actuator has been identified as the most plausible choice for a functional suspension structure because to its high potential-to-weight share and low cost. Along these lines, this model is converted to a 2 DOF QC-H-ASS with the installation of a water-powered actuator in the midst of the sprung and unsprung loads with its expert manipulation instrumentation. The results display full-size improvement in experience solace over the common inactive framework. S.H. Sawant et al. [20] analyzed the front suspension of the Hyundai Elantra 1992 model and it is doled out as 1 / 4 vehicle model and is taken into consideration for the presented observation. Demonstrating the precise exhibition of an automobile framework

addresses an unpredictable task and systems a significant boost in its plan method. This paper considers the constant response of the region automobile model shifting always over an unpleasant road for the offered take a look at. For this, a labored-on model and take a look at setup is created. The predictive impulses because of the street profile are provided by an unusual cam that delivers entry motion to the front suspension acting as a supporter of the cam. The FFT analyzer relocations on the top mount of guard were compared to the logical and MATLAB findings.

The automobile's vibration is experienced due to the engine excitation and road excitation, which can be controlled using the suspension system [21]. Here we are going to write the mathematical model of the two degrees of freedom arrangement of the car model for writing the governing equation of the damped vibrating system and modeling the 3D parts of the quarter car model using CATIA V5, which shows a better visible part and to check the natural frequency of the setup along with the simulation of the assembly [22].

3. Methodology

The governing equation of the 2 degrees of the quarter car model is written to find in the stiffness and the damping coefficient. The model of the parts like the alloy wheel and the tyre arrangement can be easily done [23]. The active spring damper, the supporting frame and the connector are designed to assemble

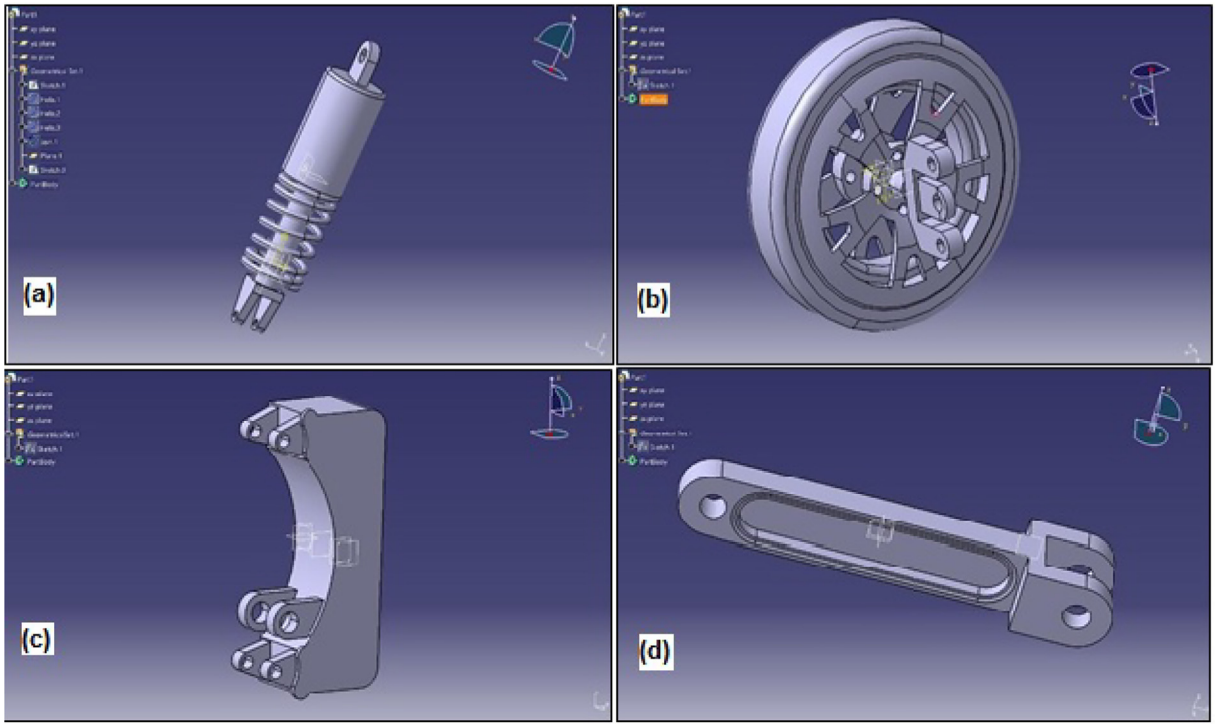

Fig. 1. 3D model of (a) spring damper (b) alloy wheel rim with tyre (c) frame (d) connector bracket.

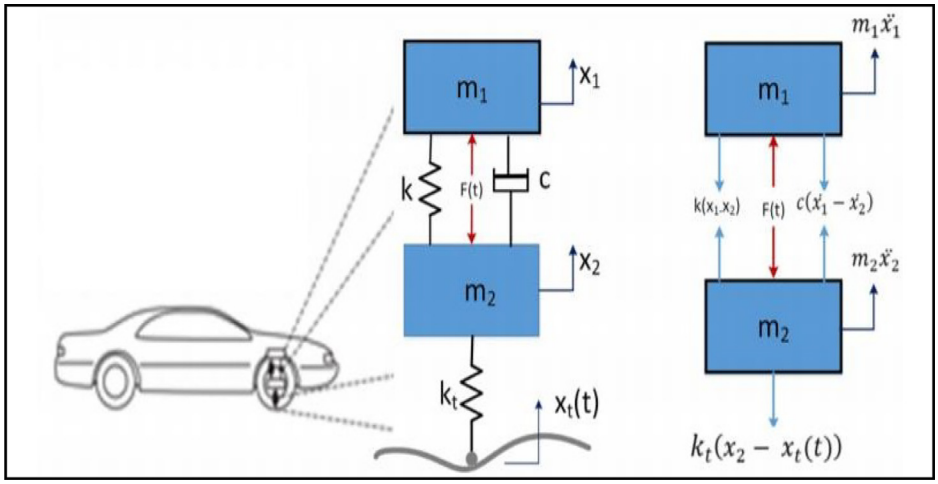

Fig. 2. Mathematical model of quarter model suspension.

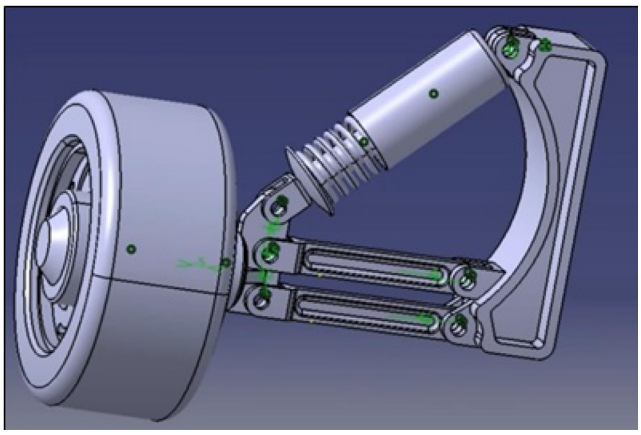

Fig. 3. Two DOF Quarter car model assembly.

the quarter car model. Here all the parts are created using the given dimensions, and the natural frequencies of the arrangement are checked. The forces exerted on the system are based on the engine excitation force and the road excitation force. The parameters like the amplitude and the frequency are measured [24]. The arrangement's behavior with the two degrees of freedom for the different excitations like the harmonic and transient excitation is checked, and the diagrams are drawn accordingly [25]. The components of the Quarter model are shown in Fig. 1 [26].

Fig. 2 depicts a quarter of an automobile suspension system. The constant spring indicates the suspension spring's elasticity, while the spring k_t represents the tire's elasticity and $x_0(t)$ is the displacement caused by the road's surface irregularity. The actuator force F, which is applied between the sprung and unsprung masses, is regulated by feedback and is one of the suspension system's active components [27,28].

4. Result and discussions

In the quarter model assembly shown in Fig. 3 vibration absorption, the helical spring used in the damper plays a major role in reducing the vibration. Hence, we have modelled the spring material with three different materials: steel, aluminium and composite and then, structural analysis. The results of the von-mises stresses and the translation displacement are compared for each material, and the stiffness values are calculated and optimized.

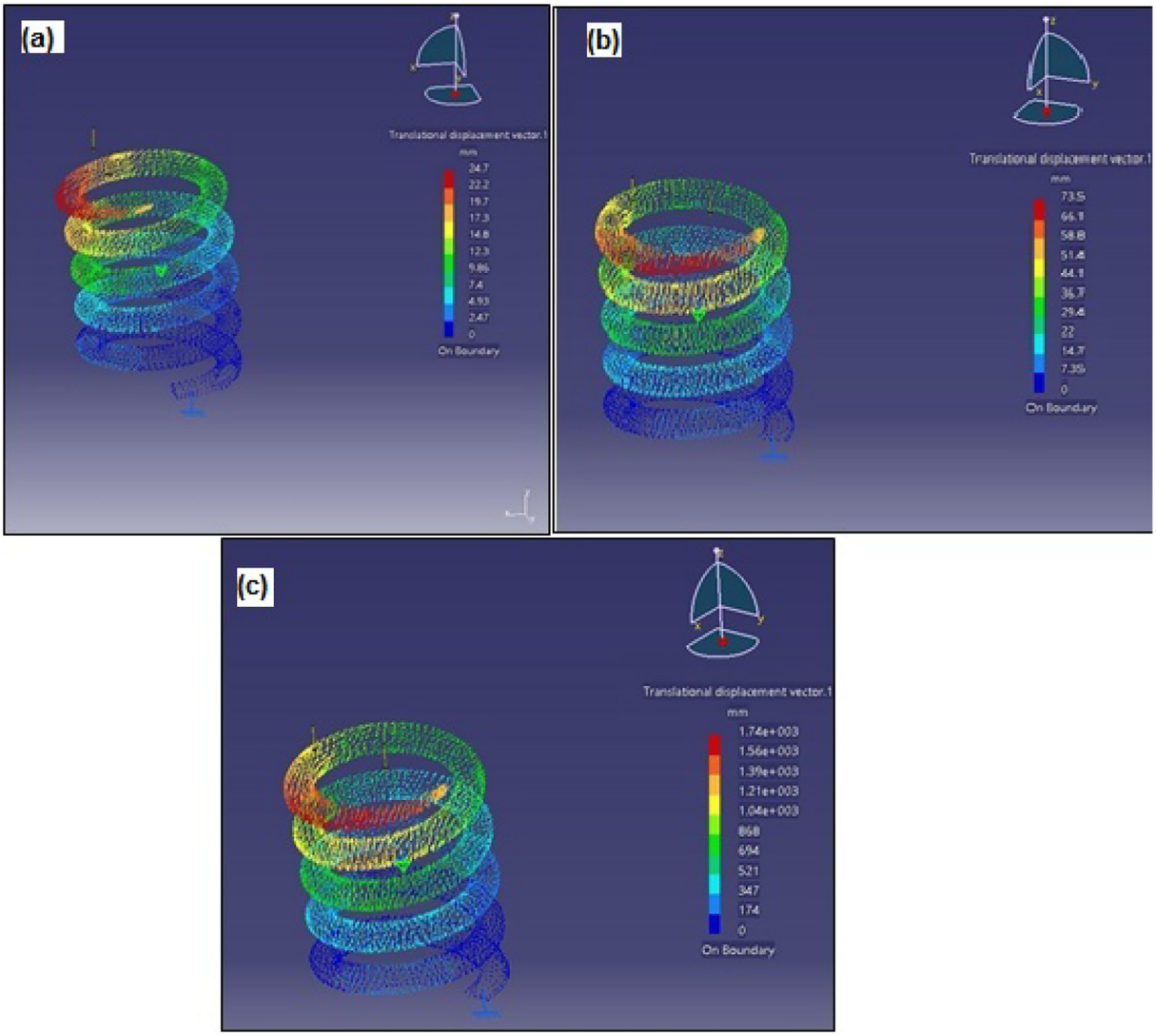

Fig. 4. Translational displacement for (a) steel (b) aluminium (c) epoxy.

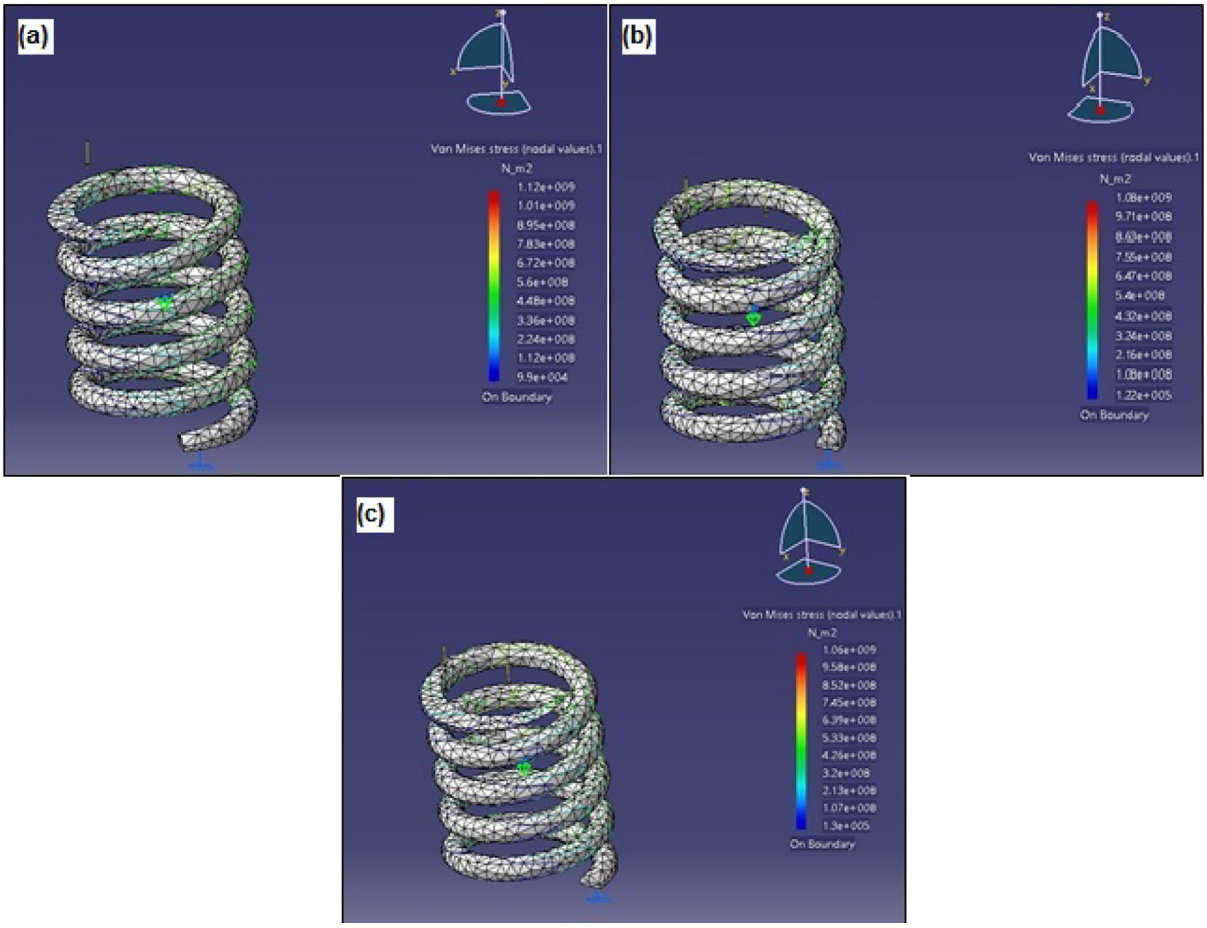

Fig. 5. Von-mises stress for (a) steel (b) aluminium (c) epoxy.

Table 1
Comparison of results.

Steel Material		Aluminum Material		Epoxy Composite Material	
TransDisplacement (mm)	Von-mises Stress (N/mm^2)	Trans Displacement (mm)	Von-mises Stress (N/mm^2)	TransDisplacement (mm)	Von-mises Stress (N/mm^2)
24.7	1.12 $x10^9$	73.5	1.08 $x10^9$	1.74 $x10^3$	1.06 $x10^9$
22.2	1.01	66.1	9.71 $x10^8$	1.56	9.58 $x10^8$
19.7	8.95 $x10^8$	58.8	8.63	1.39	8.52
17.3	7.83	51.4	7.55	1.21	7.45
14.8	6.72	44.1	6.47	1.04	6.39
12.3	5.6	36.7	5.4	868	5.33
9.86	4.48	29.4	4.32	694	4.26
7.4	3.36	22	3.24	521	3.2
4.93	2.24	14.7	2.16	347	2.13
2.47	1.12	7.35	1.08	174	1.07
0	9.9 $x10^4$	0	1.22 $x10^5$	0	1.3

The analysis of the model using CATIA is done, and Fig. 4 shows the displacement for the different spring materials such as steel, aluminium and epoxy material. Similarly, Fig. 5 show the von-mises stress for the different spring material, such as steel, aluminium and epoxy materials. Since the spring materials contribution is more in controlling the vibration, the three types of materials are checked for the structural analysis and the values are shown in the Table 1.

As a comparison of the material's behaviour of the displacement and stresses, the values are compared in the graph shown in Fig. 5 for the steel material, aluminium material and epoxy composite material. Comparatively among three materials, the steel and aluminium material has a good damping property than the epoxy materials, and mostly the steel material is recommended though the emerging composite polymers are replacing the existing automobile part as the advantage of lightweight and strength it is not many suites for the application of spring type materials.

5. Conclusions

As the quarter model car suspension is one of the recommended models that can predict the vibration-absorbing capacity for better vehicle comfort, the mathematical model has been used for 2 DOF as a sample. As the spring is one of the major components con-

tributing to the vibration reduction and shock absorption, the materials analyzed such as analyzed three materials like the steel, aluminium and epoxy materials, the steel and aluminium are better. An attempt was made to analyze the epoxy material, which the deformation is more and can be rectified by adding reinforcing materials to improve the damping characters.

CRediT authorship contribution statement

M. Muzakkir Ahamed: Conceptualization, Methodology, Supervision. **L. Natrayan:** Investigation, Data curation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] M.E.H. Jamadar, R.M. Desai, R.S.T. Saini, H. Kumar, S. Joladarashi, Dynamic analysis of a quarter car model with semi-active seat suspension using a novel model for magneto-rheological (MR) damper, J. Vib. Eng. Technol. 9 (1) (2021) 161–176.

[2] Francis Luther King, M., Putta Nageswara Rao, Sivakumar, A., Vamsi Krishna Mamidi, Richard, S., Vijayakumar, M., Arunprasath, K., Kumar, P.M., Thermal performance of a double-glazed window integrated with a phase change material (PCM), Mater. Today-Proc. (2021). 10.1016/j.matpr.2021.09.099.

[3] S. Nandhakumar, S. Seenivasan, A.M. Saalih, M. Saifudheen, Weight optimization and structural analysis of an electric bus chassis frame, Mater. Today Proc. 37 (2021) 1824–1827.

[4] M. Kuppusamy, T. Ramanathan, Experimental analysis of the thermal-barrier coating for an Al2O3-TiO2 ceramic coated ci engine operating on calophyllum inophyllum oil, Mater. Technol. 55 (1) (2021) 121–126.

[5] K.B. Prakash, C. Subramaniayan, M. Chandrasekaran, P.M. Kumar, M. Saravanakumar, Development of mathematical model to study the effect of indoor air quality parameters and optimization using response surface methodology, Mater. Today Proc. (2021), https://doi.org/10.1016/j.matpr.2021.03.087.

[6] R. Thirumalai, M. Seenivasan, A. Sivakumar, Study and analysis of safety management system at granite mining industry using non-conventional machining process, Mater. Today Proc. (2021), https://doi.org/10.1016/j.matpr.2021.05.207.

[7] R. Raj Mohan, R. Venkatraman, S. Raghuraman, P.M. Kumar, M.L. Rinawa, R. Subbiah, B. Arulmurugan, S. Rajkumar, H.B. Jiang, Processing of Aluminium-Silicon Alloy with Metal Carbide as Reinforcement through Powder-Based Additive Manufacturing: A Critical Study, Scanning 2022 (2022) 1–14.

[8] R. Thirumalai, C. Sadhasivam, Experimental Measurement and Computational Investigation on the Effect of Inlet Winglet Turbulators on the Heat Exchange Behaviour of Radiator of Tubes. J. Appl. Fluid Mech. 11 Special Issue, (2018), 135–139.

[9] V. Paranthaman et al., Effect of silica content on mechanical and microstructure behaviour of resistance spot welded advanced automotive TRIP steels, Silicon (2021) 1–10.

[10] P. Sureshkumar, T. Jagadeesha, L. Natrayan, M. Ravichandran, D. Veeman, S.M. Muthu, Electrochemical corrosion and tribological behaviour of AA6063/Si3N4/Cu(NO3)2 composite processed using single-pass ECAPA route with 120° die angle, J. Mater. Res. Technol. 16 (2022) 715–733.

[11] Viswanth.K.Allamraju, Modal analysis of quarter car model suspension system, Int. J. Eng. Sci. Res. Technol. Thosonreuters July 2016.

[12] A.N. Thite, Development of a Refined Quarter Car Model for the Analysis of Discomfort due to Vibration, Adv. Acoust. Vib. 2012 (2012) 1–7.

[13] D. Ramya, A. Krishnakumari, P.T. Dineshkumar, M.P. Srivastava, L. Vadivel Kannan, G. Puthilibai, P. Manoj Kumar, Investigating the influence of nanoparticle disbanded phase changing material (NDPCM) on the working of solar PV, Mater. Today Proc. 56 (2022) 1341–1346.

[14] Abdolvahab Agharkakli et al Simulation and Analysis of Passive and Active Suspension System Using Quarter Car Model for Different Road Profile, Int. J. Eng. Trends Technol. 3 (5) (2012), 636–644.

[15] P.T. Saravanakumar, S.P. Arunkumar, B.B. Mansingh, P.M. Kumar, R. Subbiah, V. K. Eswarlal, Investigating the effect of thermal cycling on thermal characteristics of the nano-silica based phase changing material (PCM), Mater. Today Proc. 50 (2022) 1502–1507.

[16] P. Sathishkumar et al., Mathematical modelling and simulation quarter car vehicle suspension International Conference on Engineering Technology and Science, Volume 3, Special Issue 1, February 2014, 1280–1283.

[17] A. Mitra et al., Simulation and Analysis of Full Car Model for various Road profile on a analytically validated MATLAB/SIMULINK model, J. Mech. Civil Eng. 22–33.

[18] V.M. Barethiye et al. , Analysis of a quarter car suspension system based on nonlinear shock absorber damping models, Int. J. Autom. Mech. Eng. 14 (3) September (2017), 4401–4418.

[19] S.A. Patil, S.G. Joshi, Experimental analysis of 2 DOF quarter-car passive and hydraulic active suspension systems for ride comfort, Syst. Sci. Control Eng. Open Access J. 2 (1) (2014) 621–631.

[20] S.H. Sawant et al., vibrational analysis of quarter car vehicle dynamic system subjected to harmonic excitation by road surface, Int. J. Instrument. Control Autom. 1 (3,4) (2012) 14–16.

[21] D. Mohankumar, Y. Pazhaniappan, R.N. Kumar, R. Ragul, P.M. Kumar, P.N. Babu, Computational study of heat-transfer in extended surfaces with various geometries, IOP Conf. Ser-Mat. Sci. 1059–1 (2021), https://doi.org/10.1088/1757-899X/1059/1/012055 012055.

[22] P.M. Alexander, S. Nandhakumar, S. Seenivasan, N.A. Ahamed, P.R. Kumar, Optimal orientation of injectors for efficient spray pattern of fuel flow in a diesel engine, Mater. Today Proc. 37 (2021) 2890–2896.

[23] L. Natrayan et.al, Enhancement of Mechanical Properties on Novel Friction Stir Welded Al-Mg-Zn Alloy Joints Reinforced with Nano-SiC Particles, J. Nanomater. vol. 2021, Article ID 2555525, 10 pages, 2021.

[24] M.K. Pasupathi, K. Alagar, M. Mm, G. Aritra, Characterization of Hybrid-nano/Paraffin Organic Phase Change Material for Thermal Energy Storage Applications in Solar Thermal Systems, Energies. 13–19 (2020) 5079, https://doi.org/10.3390/en13195079.

[25] Anjibabu Merneedi et.al, "Free Vibration Analysis of Thick Rectangular and Elliptical Plates with Concentric Cut-Out", Adv. Mater. Sci. Eng. vol. 2021, Article ID 7212075, 14 pages, 2021.

[26] M. Balaji, S.N. Dinesh, S.V. Vetrivel, P.M. Kumar, R. Subbiah, Augmenting agility in production flow through ANP, Mater. Today-Proc. (2021), https://doi.org/10.1016/j.matpr.2021.06.053.

[27] V. Paranthaman, K.S. Sundaram, L. Natrayan, Influence of SiC particles on mechanical and microstructural properties of modified interlock friction stir weld lap joint for automotive grade aluminium alloy, Silicon 14 (4) (2022) 1617–1627.

[28] P.M. Kumar, A. Karthick, S. Richard, M. Vijayakumar, P.M.J. Stalin, D.G. Kumar, G. Aswanth, M. Aswath, V.K. Eswarlal, Investigating performance of solar photovoltaic using a nano phase change material, Mater. Today Proc. 47 (2021) 5029–5033.