Jestr

Journal of Engineering Science and Technology Review 15 (2) (2022) 184 - 190

Research Article

JOURNAL OF
Engineering Science and Technology Review

www.jestr.org

Improvement of Vehicle Crashworthiness by Polyurethane Foam as a Highly Efficient Energy Absorber in the Side Impact Crash

Rajesh V. Patil

School of Mechanical - Robotics and Automation Engineering, Dr. Vishwanath Karad , MIT World Peace university , Pune

Received 10 October 2020; Accepted 11 June 2022

Abstract

The most critical accidents are generally found by the side impact crashes in automotive and more than 30% loss of life due to road accidents using passenger cars and light trucks. Various assemblies introduced to attain safety by sidebars, crumple zones, crash cones and energy absorbing padding. But during event of crashes, generally foam used to absorb energy and also set to dummy motion. When vehicle hit on another vehicle, initially dummy thrown towards impacting vehicle, then pelvis of dummy hits doors panel and at this time foam will absorb impacting energy and helps dummy to move on opposite directions. The padding usually applied and located in the vehicle door for securing the pelvis, the abdomen and thorax area. The proposed work presented behaviors of polyurethane foam padding by quasistatic compression testing and observed under impact in simulated environment. Different combinations of foam material along with various density used for compression testing by universal testing machine. At last, composite polyurethane foam block III found as highly efficient energy absorber composite polyurethane foam for side impact crash. Hyper mesh used for meshing and LS Dyna represented material model inputs for dynamic impact testing.

Keywords: Composite polyurethane foam, side impact crash, energy absorber, quasi static compression, polyurethane foam behavior, vehicle crashworthiness.

1. Introduction

The demand of cellular materials of polymeric foams growing significantly since few eras. These materials are used in automotive for many applications such as thermal insulation, vibration damping, fire shield, crashworthiness and energy absorption. Therefore crashworthiness, security and shield parameters are sturdily influenced by proposed materials. Polymeric foams play a crucial part in the automobile's crashworthiness and tenant safety. The energy absorption of proposed materials significantly improves vehicle passive safety and well shielding the passengers from destructive effects. In adding, design boundaries due to ecological restrictions enlarged as far as protection concerned. Therefore, the combination of properties with great energy absorption capability which makes cellular material an appropriate selection of automotive industries. In many cases, automobile manufactures answerable for the advancement relating to safety. Generally, the gate system mandatory to give a positive load-intrusion distinctive to an unyielding impactor. This distinctive further used for pelvis, abdomen, thorax part and finally suitable loads through side impact to dummy outcome of targeted level of damage parameters achieved. To design for side impact collision the major limitation is to restrict crumple zone in between impacting vehicle and tenant. A proper control of padding stiffness is very important especially for abdomen & pelvis protection. An ideal energy engrossing material wants to dissipate kinetic energy of impact whereas keeping force on it lower some typical confines. The design of operative padding involves shape of protective structure, capacity to engross elastic energy and controls rebound considerations. Mostly, plastics and aluminum are used with consideration of the space availability and weight of the part to be used as absorbing material in the side impact crash. This condition satisfies by polymeric materials such as foams because of foam behaviour depends on its density and combined density, which can be used for absorbing maximum energy.

The statistical data analysis of accidents and decrease of impact energy stated that accident by the side impact crashes. Some of researchers investigated the material behaviour and padding characteristics in impact conditions. Kedir, M., [1] presented mainly FEA of a stiff polyurethane foam under impact loading. Energy absorption capacity of a rigid polyurethane foam measured both under impact weight of a drop mallet and a passenger wagon with mass of 1200 and 2000 kg and speed of 30 and 50km/hr. In the absenteeism of field crash trials principle of energy conservation authenticate established FE models. Andrew, H. et.al [2] suggested super-lightweight cars may position substantial danger to the occupants if they are available in a crash. The tests should comprise slanted and numerous velocity effects to provide for effects of supported driving schemes of upcoming vehicles.

Sahil G. et.al. [3] fabricated star polygonal shape thin enclosed energy absorption assembly inclines to decline the strength of set in slowing down during effect while rising the quantity of energy captivated. They found 40% increase of specific energy absorption choice of a specific sort of foam over a hollow tube. Samet D. et.al. [4] investigated the cyclic fatigue presentation of six diverse polyether sort of polyurethane foams. The outcomes presented that growing the density of the standard foam from 14 kg/m3 to 28 kg/m3 lessening the 25% indentation force deflection damage no. of the foams from 30.7 to 21.5%, which enlarged foam

*E-mail address: patilraje@gmail.com
ISSN: 1791-2377
doi:10.25103/jestr.152.21

firmness. Jiye C., et al. [5] proposed on the energy absorption features of four sorts of advanced foam-filled many cell composite panels. Numerous mathematical simulations using LS-DYNA shown on the foam occupied many cells composite panels with dual layer displacement cells to constant examine the properties of the face sheet and lattice-web width, the foam-cell tallness, thickness, and density. Srinivasa S. et.al [6] observed C part has a smaller amount stress count than of further cross section. The dual C part found the stress count are a bit larger than C part but the strain energy is enlarged by 4.5%. It positioned on the collection of bumper beams under variable limits such as form and material to provide the requirements of safety through phase of product plan description. Vivek Srivastava et al. [7] proposed prominent replacement of metal in expanded polypropylene for extensively bumpers and passenger safety application to experience large multi-axial deformation at high strain rates. E Linul et al. [8] studied diverse factors those influences polyurethane foam mechanical properties under dynamic compression and analysed the density effect, loading amount, material direction and temperature under active compression behaviour of inflexible polyurethane foams. M. Avalle et al. [9] determined density as a key parameter affects the foams behavior through mechanical properties and impact state of microcellular structural foam. Xinzhu Wanget et al. [10] investigated uniaxial compression and indentation response under quasistatic loading conditions of closed-cell aluminum foams. They found indentation distortion limited to a spherical cap shape compact zone under indenter. Kwang et al. [11] examined the strain rate reliant on behaviour of polyurethane foams and formulates a novel constitutive model appropriate to advance fitting of investigational data at several strain rates. Marcin Jankowski et al. [12] explained constitutive model of compression which assumed that density, component part and strain rate are divisible functions and verified by experimental results of static tests. Mariana Paulino et al. [13] proposed the energy engrossed by vehicle worldwide assembly, in which polyurethane foam material exhibited finest behavior with presence of padding and micro group stopper padding caused enhancements of almost 13%. Goga vladimir et.al [14] measured the energy absorption of polyurethane foam. The compression of foams by impact test found and absorbed all kinetic energy of fall down mass. Finally, kinetic energy compared with energy calculated by compressive stress strain curves. Gerhard slik et. al. [15] proposed the energy absorbing foam padding applied as a passive safety system in automotive and have done a physical test as a drop tower test for defining the material properties. Hou Zhi-chao et.al.[16] projected quasistatic stress strain relation of polyurethane foams in terms of fractional calculus. An indentation force deflection test conducted on polyurethane foams for passenger vehicle seats. To address the stress-strain relation, a power polynomial of strain describes non linear elasticity of material, while a fractional calculus used to reflect the linear viscoelasticity of foam. Soonsung Hong et. al. [17] investigated tensile distortion and fracture behavior of closed cell unyielding polyurethane foam. The determination of crack-tip parameters using digital image correlation and conservation integrals proved tool to characterize and investigate fracture processes in polymer foams. Also, they mentioned from regulation norms the side bars, crash cones, and side air bags also used for side impact protection. Vivek Srivastava et al. [18] investigated change in performance of expanded polypropylene by simulation modelling. They studied workforce - time, displacement, force- displacement and internal energy interactions for solid tetrahedral element. The detailed analysis of stress solid element, one-point tetrahedron and nodal pressure tetrahedron element formulation revealed that element formulation creates a considerable difference system behaviour and energy absorption capacity. Janusz L. et.al. [19] carried out fatigue tests on different foam samples and determined changes in the thickness and density. They examined effect of the volumetric compression relation on the fatigue assets of auxetic foam trials and the necessity of foam deflection on the quantity of cycles.

The objective of proposed work is to test polyurethane foam as a side impact structural scheme for maximize energy absorption. To find the foam exact position & space availability genuine door panel of hyundai verna car used as shown figure 1. The author proposed polyurethane foam having densities of 30 and 80 kg/m^3 with varying cross-sectional area. The rectangular shape selected for foam samples for easy to mount into vehicle door panel. Actual side impact damages of various car door panel as shown figure 2. The damaged area found near pelvis and lower leg part of occupant in this study.

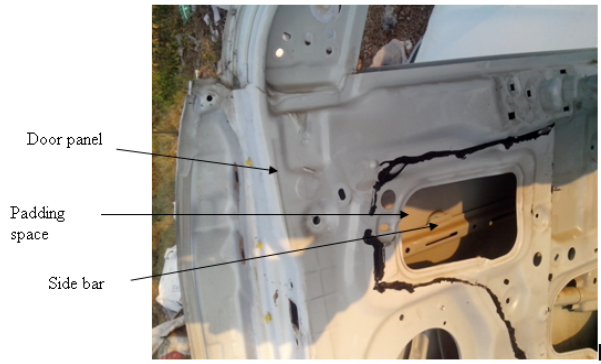


Fig. 1. Door panel of hyundai verna.

Fig. 2. Actual side impact damages of various car during field investigations.

2. Experimental investigation of polyurethane foams behaviour

The proposed closed cell polyurethane foam used for padding because of the capability to absorb shock from an impact and rapidly improve its original shape. Therefore, the physical characteristics ideally improve their protection phenomenon from side impact crashes and easily divide and fabricated to various shape & custom-fitted padding. In LS-DYNA, foams characterized by reversible behaviors having nonlinear elastic behaviour and undergoes rupture in tension and irreversible behaviors having elastic-plastic behaviour and undergoes failure in tension and shear. The proposed work selected MAT 57 materials for modelling highly compressible low density rectangular shape foams of 30 to 80 kg/m^3. It recovers entirely to its initial shape without any damage easily after loading and subsequent unloading. This model is excellently a maxwell fluid of damper and series spring and the material acts in a linear fashion until tearing occurs in tension. It's mostly selected for seat pillows and padding on side impact dummies and very robust in applications and it easy to modify its parameters. Polyurethane foam used as a padding for absorbing the impact in the side crashes and compress during impact. To check the behaviour of foam under compression and to find out responses of foam material under different load, author conducted various test by universal testing machine. The proposed polyurethane foam specification as shown table 1.

Table 1. Polyurethane Foam Parameters

Polyurethane Foam	**Specification (mm)**	**Density (Kg/m^3)**	**Load (k N)**
Block I	150 x 60 x 50	60	45
Block II	100 x 50 x 50	80	180
Block III	50 x 50 x 30	-	80

2.1. Quasistatic compression test
The proposed quasistatic test finds out the compression behaviour at low strain rates and block samples compressed at constant low velocity. The impact velocity applied in between 2 to 4 m/s on foam located between flat impactor and rigid base. Lastly determined stress strain curves of foam samples.

2.2. Dynamic compression test
The material behaviour of foam at high velocity obtained from drop tower test. Foam block samples located in between impactor and rigid base. The varied impact mass and impactor drop height resulting various impact velocity and energy. The flat impactor velocity used in between 5 to 9 m/s.

3. Compression test on polyurethane foam

The polyurethane foam blocks I and III having density of 30 kg/m^3 and 80 kg/m^3 used for compression test by universal testing machine as shown figure 3. A proposed fatigue test described in ISO 3385, ASTM D3574 standard. The block mounted in between rigid base and circular impactor with applied quasistatic load condition throughout testing phase. As per observation, resistance shown by block I is very less due to low density. The graphical representation shown displacement of block I after applied load of 45 kN and 50 mm height block almost reduced up to 46 mm. Block II having 38 kg/m^3 of density according to result obtained from block I and deformation in block II found similar nature which are not useful for absorbing impact energy. The author found not much huge difference in density of block I & II.

Therefore, block III having higher density of 80 kg/m^3 and application of loading selected as quasistatic in nature. From above testing, deformation of low and high density found. Afterwards those values used for trial and iteration purposes for finding out exact percentage of foam density model in a simulated environment. At last graphical representation found less deformation due to high density and offered high stiffness after applied load of 180 kN.

During the event of a crash, the foam used to absorb the energy and also to set dummy motion. When one vehicle hit on other's, dummy thrown towards the impacting vehicle initially. During pelvis of dummy hit on door panel. At that time foam will absorb impacting energy and helps dummy to move in opposite direction. A rigid pelvis or spherical shaped impactor designed for known mass and well-defined velocity. Figure 4 illustrates pelvic impact or load intrusion for door panel. During test, impactor acceleration and displacement recorded and calculated force from acceleration. At last data plots the load versus displacement curve and fit in to defined corridor.

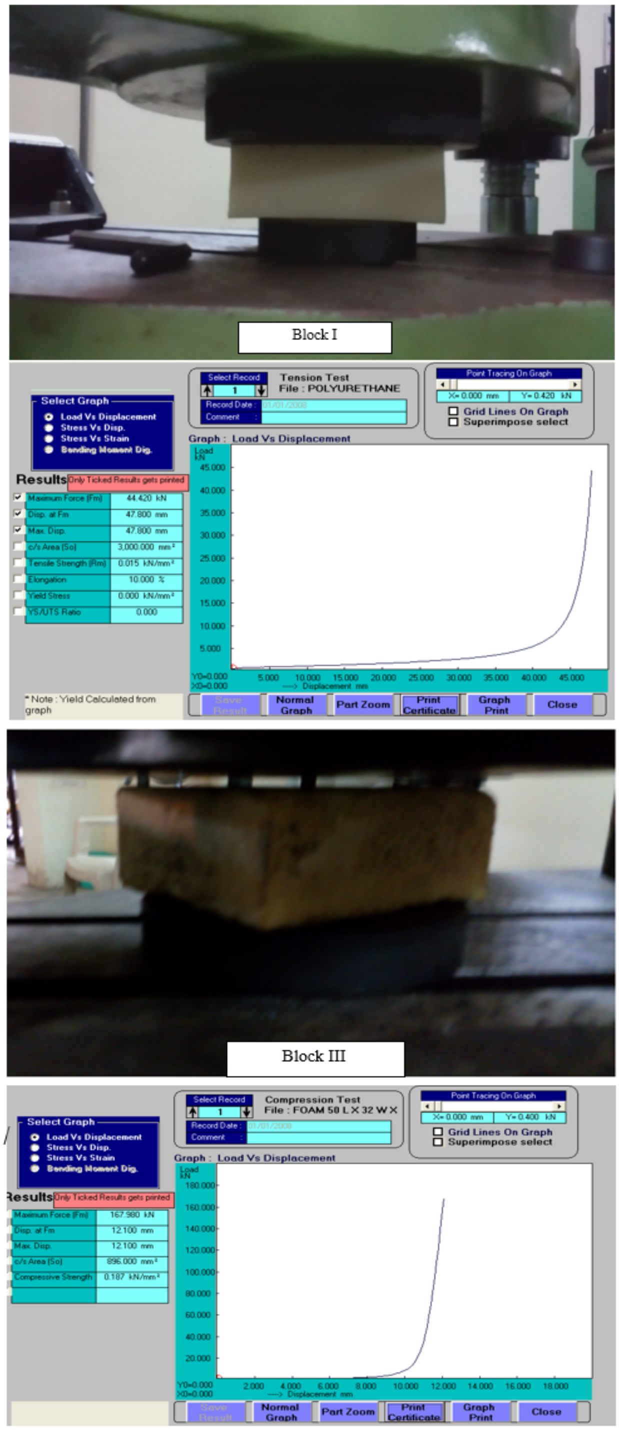


Fig.3. Compression test and behaviors of foam block I and III.

4. Polyurethane foam mesh model development

Computer aided engineering setup act as a drop tower test which used to apply impact on dynamic condition. The foam placed on a flat rigid base as shown figure 5. The rigid impactor having specific mass impacted with initial velocity to achieve desired energy. Finally, deformation patterns of foam observed from test.

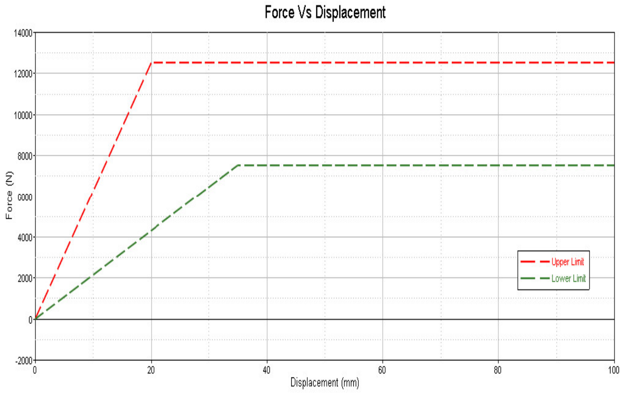


Fig.4. Targeted behaviour of polyurethane foam after impact test.

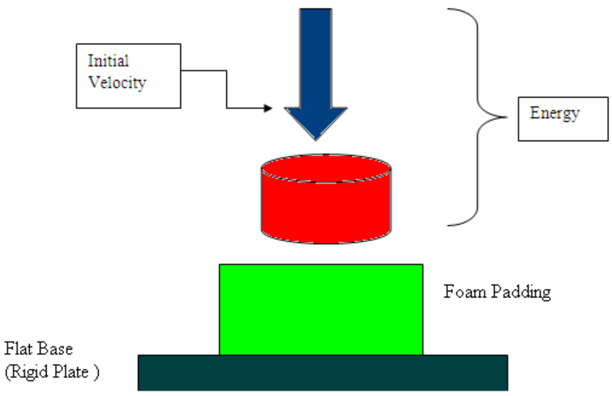


Fig 5. Schematic representation of CAE set up.

A crash test model built by LS-DYNA. An impactor designed for load of 20 kg and fall on trim section with some velocity. The velocity adjusted until foam absorbed 690 Joule energy. The impactor made rigid and assumed that body in white (BIW) will not move hence it is also made rigid. The impactor assumed to be made of similar material as door trim.

4.1. Mesh Model for Foam blocks I and III

The polyurethane foam mesh model and force versus displacement graph for 30 and 80 kg/m^3 as shown figure 6. BIW used as a base and foam mounted in between doors panel and BIW. The impactor used as dynamic condition for foam. The upper and lower limit set according to the safety standards of different regulatory norms and limit study are already made related to human biomechanics. Due to less stiffness of foam, deformation is more and defined foam absorbed less amount of energy. The obtained curve of force versus displacement displayed outside the defined corridor and design model for density of 30 kg/m^3 found unappropriated. Furthermore, density of 80 kg/m^3 mesh model, along with stiffness and position of mounting considered same as like for first block. The force versus displacement graph shown less deformation and more load carrying capacity. It means it's stiffer in nature and unfit to mentioned tolerance limit safety zone.

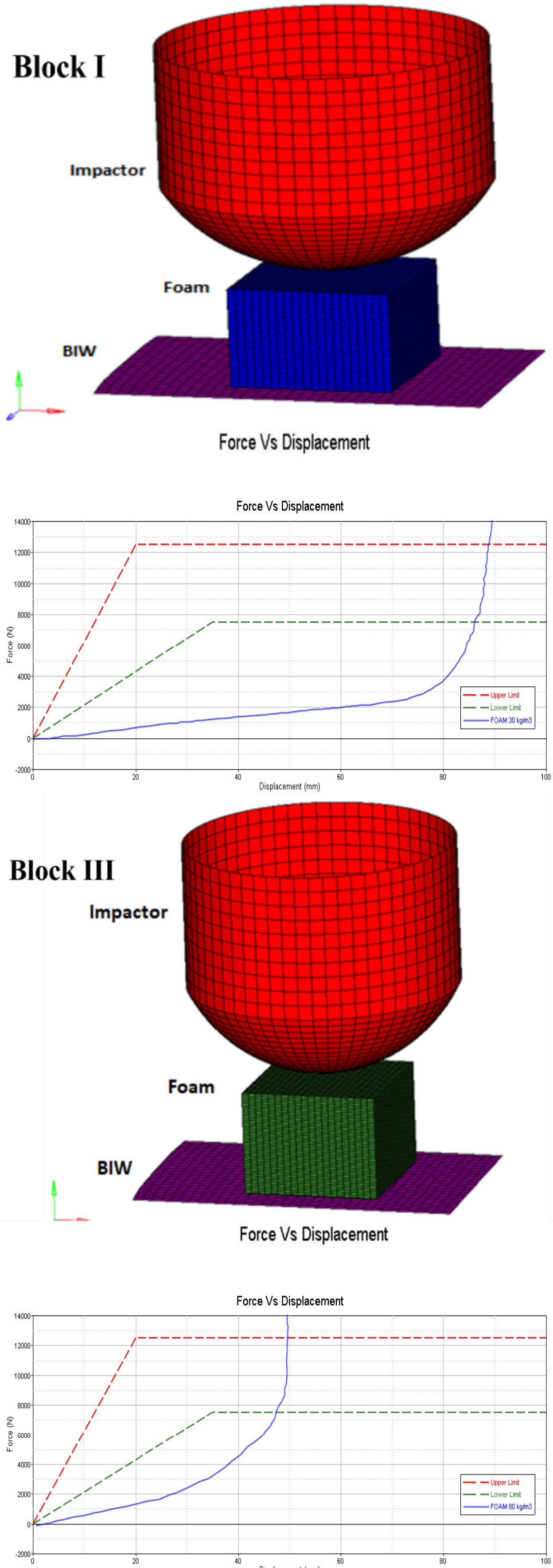
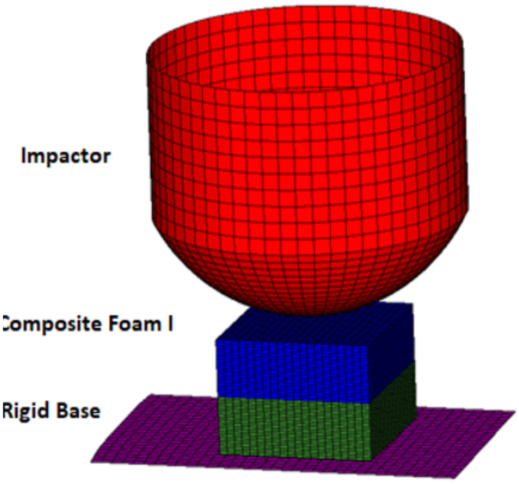
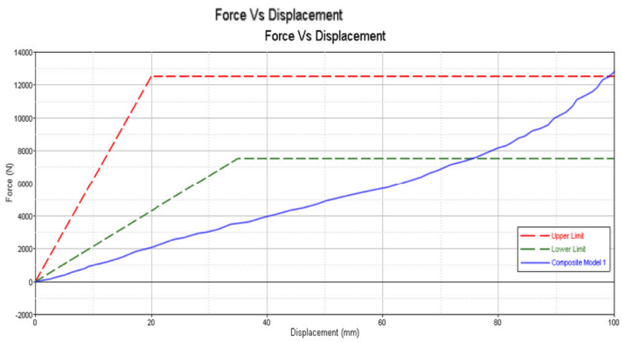


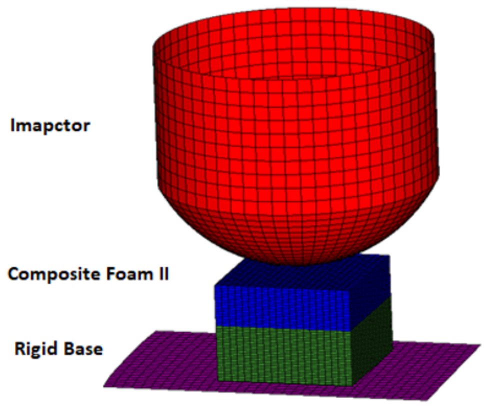
Fig. 6. Mesh model and graphical representation foam block I and III.

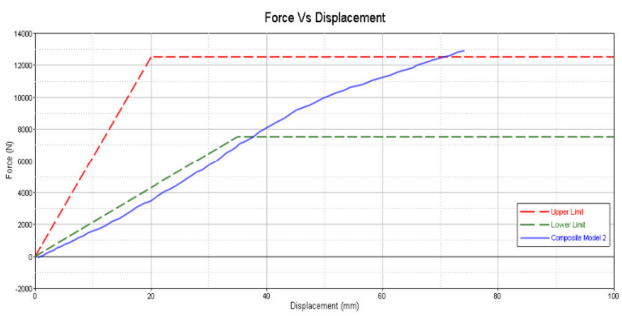
4.2. Behaviuor examination of composite model iii

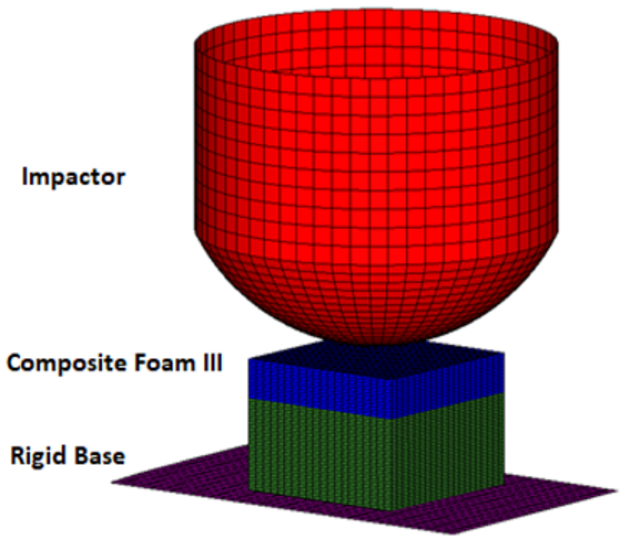
The universal testing machine used to conduct compression test for composite block III. The impact absorbing side having stiffer foam and occupant side less stiff foam placed. The foam having less stiffness is completely deformed and at the same time foam having high stiffness deformed partially and absorbs maximum amount of energy found as shown figure 9 (a) and 9(b). Finally, author found stiffer foam absorbed maximum amount of energy and deformed whereas, soft foam deformed initially and reach afterwards to its original shape.











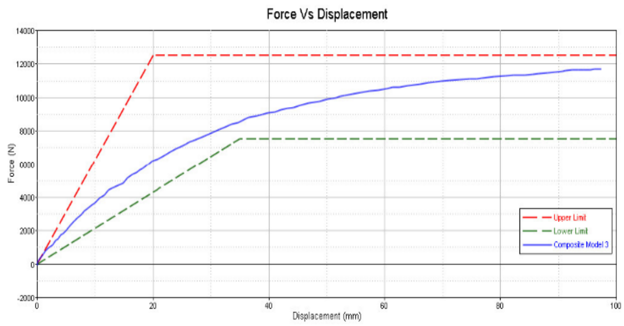
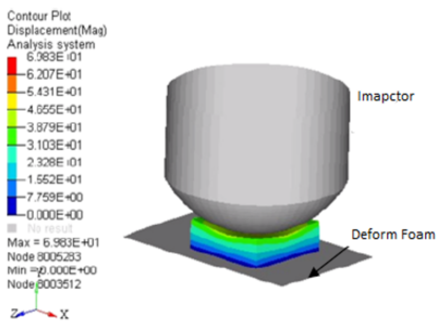


Fig. 7. Mesh model and graphical representation Composite Foam Block I, II and III.



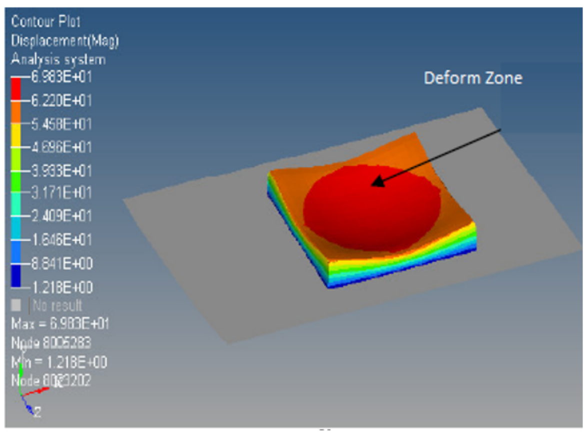


Fig. 8. Deformation due to absorption of impact energy after impact load.

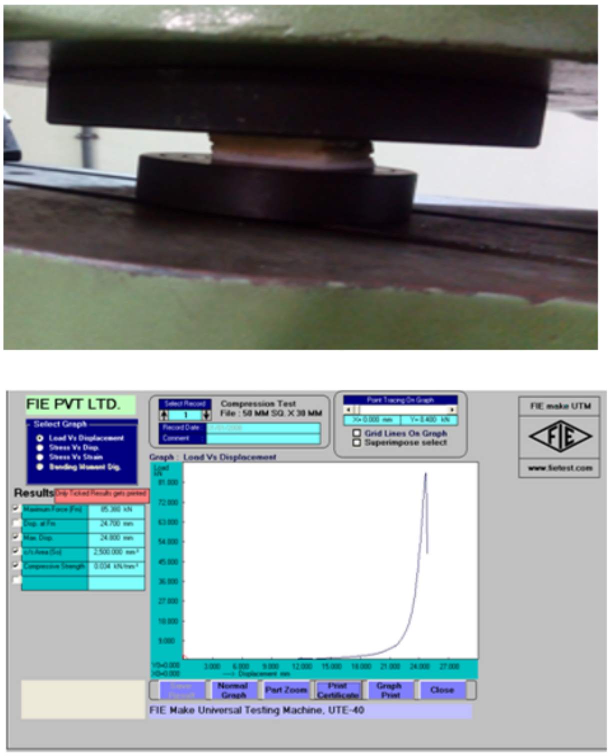


Fig. 9. Compression test and behaviors of composite foam III.

5. Discussion

The comparison finished by all curves and effectively determined composite model curve in between obtained two curves of high- and low-density polyurethane foams. In the present work block I having density of 30 kg/m^3 deformed more as compared to density having 80 kg/m^3 of block III. The load absorbed very low and deformed more by foam block I as compared to foam block III. As many other researchers have been found with density of 20kg/m^3, 30kg/m^3, 40kg/m^3 deformed more as compared to density having 50kg/m^3, 60kg/m^3, 70kg/m^3 with not only MAT57 but also with MAT073, MAT083, IMPAXX 300, IMPAXX 500 and IMPAXX 700 materials. In this case the risk of injury on the occupant is more and need to propose a composite as an alternative solution for achievement of efficient energy absorption in vehicle side door panel. So, to determine the combine effects, composite foam calculated appropriate results in terms of energy absorption and deformation. The composite foam models validated against initial two foam block having different density. Furthermore, foam blocks I & block III having low and high stiffness determined inconvenient for applications.

In next phase, combination of foams to become a single model to absorb appropriate energy proposed. These tests observed composite model I having equal densities of low and high stiffness. Furthermore, composite model increases percentage of stiffness foam and found closer to final outcomes. The foam having high stiffness increased up to 67% and low stiffness reduced up to 33% called as composite model III. This combination results found within tolerance limits and highly efficient foam padding design for energy absorber in side impact crash as shown figure 10. At last, the comparison made with the present and other researcher work results have been found, the composite foam absorbs more energy and deformation sustained by the composite foam is more which initiate reduction in the displacement and acceleration of car is about 55%. The injury levels also reduced upto 65% introducing proposed composite foam. Finally, the cost is also reduced upto 10 % by using this foam.

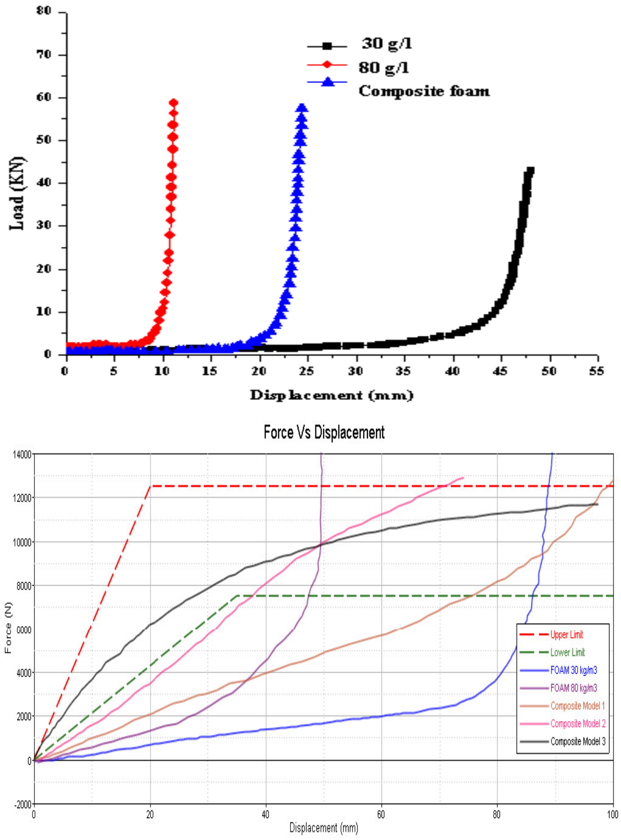


Fig 10. Performance comparison and its behavoiurs for all foam blocks.

6. Conclusion

The following conclusions made from proposed work.

1. Introduction of polyurethane foam inside the sideways doors of all automobiles recommended as an inactive protection mechanism in side impact automobile to automobile crashes. Outcomes found that application of a foam alike a cellular material as a padding for energy dissipation in side gates, in fact, mainly significant enhancements in terms of extreme values of deceleration and loads conveyed to the tenants of vehicle.
2. Composite polyurethane foam proved highly efficient energy absorber for side impact crash.
3. The polyurethane foam having density of 80 kg/m^3 as high stiffness increased up to 67% and other having density of 30 kg/m^3 as less stiffness reduced upto 33%. Using composite foam model III, results found within tolerance limits and highly efficient foam padding design for energy absorber for side impact crash achieved.
4. The proposed test by quasistatic compression and dynamic impact sucessfully proved functionality of composite polyurethane foam by their density performance.

References

1. Kedir, M., Energy Absorption Capacity of Rigid Polyurethane Foam under Impact Load, Indian Journal of Advanced Mathematics, Vol. 1,1, April 2021, pp.8-14.
2. Andrew, H., Jesper, C., Christophe, B., and Stratis, K., Crashworthy structures for future vehicle architecture of autonomous pods and heavy quadricycles on public roads: A review, Proc IMechE Part D: J Automobile Engineering, Vol. 234(1), 2020, pp. 3–16.
3. Sahil, G., Anand C., Sunilkumar, and S., Rakesh, S., Crashworthiness analysis of foam filled star shape polygon of thin-walled structure, Thin-Walled Structures, Vol. 144, November 2019, 106312.
4. Samet, D., and Busra E., Evaluation of the cyclic fatigue performance of polyurethane foam in different density and category, Polymer Testing, Vol. 76, July 2019, pp.146-153.
5. Jiye C., Hai Fang, and Weiqing L., Energy absorption of foam-filled multi-cell composite panels under quasi static compression, 2018 Composites Part B, 153, ,2018, pp. 295–305.
6. Srinivasa S., Viswatej, K., and Adinarayana S., Design and Sensitivities Analysis on Automotive Bumper Beam Subjected to Low Velocity Impact", International Journal of Engineering Trends and Technology, V37(2), July 2016, pp. 110-121.
7. Srivastava, V. and Srivastava, R., Performance evaluation of fu chang and low density foam model for expanded polypropylene,International journal of mechanical engineering 2014, 4 (1):, 49–53.
8. Linul, L., Voiconi, T., and Sadowski, T., Study of factors influencing the mechanical properties of polyurethane foams under dynamic compression, Journal of Physics Conference Series 2013, 451; 234- 239.
9. Avalle, M. and Scattina, A., Mechanical properties and impact behavior of a microcellular structural foam, International Journal of Impact Engineering, 2013, 20; 114- 131.
10. Xinzhu W. and Guangtao , Z., The static compressive behavior of aluminum foam, Advanced study centre , Rev. Advance Materials Science 2013 , 33; 316-321.
11. Kwang, Y.J., Seong, S.C., and Mahbubul, B. M., A constitutive model for polyurethane foam with strain rate sensitivity, Journal of Mechanical Science and Technology 2012, 26 (7) ; 2033- 2038 .
12. Marcin, J., Leszek, C. and Maria, K.,Numerical simulation of energy absorption in polyurethane foams under impact , Journal of kones powertrain and transport, 2012, 19; 127-135.
13. Mariana Paulino and Filipe Teixeira-Dias , On the use of polyurethane foam paddings to improve passive safety in crashworthiness applications, Paulino and teixeira-Dias, licensee In Tech Polyurathane 2012 ; 337-354.
14. Goga, V., Measurement of the energy absorption capability of polyurethane foam, Portal pre odborne publikovanie 2010 ; 440-447.
15. Gerhard, S. and Gavin V., Material model validation of high energy absorbing foam ,Dow automotive 2009, 2 ; 90–97.
16. Hou, Z., Han-kee and Gao J., Quasi-static stress-strain relation of polyurethane foams in terms of fractional calculus , 3rd International Conference on Integrity, Reliability and Failure, Porto/Portugal 2009 ; 23-33.
17. Soonsung Hong, Helena Jin, Wei-Yang Lu , Full-field characterization of tensile and fracture behavior of a rigid polyurethane foam using digital image correlation, Proceedings of the XI th International Congress and Exposition , 2008 87-99.
18. Srivastava, V., Srivastava, R., and Mohd. A. Khan, A Numerical study on influence of solid element types with expanded polypropylene , Motilal nehru national institute of technology, Allahabad, 2007 ; 1-7.
19. Janusz, L, Dominik N., and Piotr, R., Fatigue properties of polyurethane foams, with special emphasis on auxetic foams, used for helicopter pilot seat cushion inserts, Fatigue of Aircraft Structures, Vol. 1, 2014, pp.72-78