CRASHWORTHINESS PERFORMANCE OF OPTIMIZED AUXETIC FOAM-FILLED TUBES UNDER AXIAL LOADINGS

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DEDICATION

To my beloved parents, brother and wife

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ABSTRACT

Filling thin-walled tubes with foam cores is a typical method to promote a desirable energy absorption performance and stabilize the crushing responses of thin-walled tubes under impact loading. Auxetic foams as new class of cellular materials have recently gained popularity within the research community due to their enhanced mechanical properties. However, the energy absorption performance of auxetic foam-filled tubes design information is very limited. The aim of this study is to evaluate the crush response, the energy absorption capacity and the deformation behavior of auxetic foam-filled square and circular tubes under quasi-static and dynamic axial loadings. For comparison, energy absorption performance of empty and conventional foam-filled square and circular tubes was also experimentally and numerically examined with respect to deformation modes and load-displacement responses. All tube specimens were crushed at a constant loading rate of 3 mm/min for quasi-static loading and an initial impact velocity of 5 m/s was adopted for dynamic loading. In order to investigate the influence of tube effective parameters such as wall thickness, diameter, width and height, a series of parametric studies were conducted using validated finite element (FE) models. The initial finding reveals that both auxetic foam-filled square and circular tubes are superior to empty and conventional foam-filled tubes in terms of energy absorption capacity without a significant increase in the initial peak load. From the initial finding and due to the great potential of auxetic foam as cores, a new fabrication technique called Quasi Tri-axial Compression Method (QTCM) was developed to fabricate the auxetic foam with the maximum achievable negative Poisson's ratio. The fabricated auxetic foam with optimal re-entrancy was then introduced as the core for the tubes. Moreover, energy absorption capacity of auxetic foam-filled tubes was experimentally quantified with the foam Poisson's ratio ranging from -0.13 to -0.32. The results show that the energy absorbed by auxetic foam-filled square and circular tubes loaded dynamically are approximately 34.7% and 22% greater than that of conventional foam-filled square and circular tubes respectively. This is practically beneficial when higher kinetic energy needs to be absorbed in order to reduce the impact force transmitted to the occupant's compartment. Furthermore, it is evident that an increase in the auxeticity level of foam filler enhances crashworthiness performance of filled tubes under both quasi-static and dynamic loading conditions. Above all, the primary outcome of this thesis is a design guideline for the use of an auxetic foam as a core for energy absorbing devices where axial impact loading is anticipated.

ABSTRAK

Pengisian tiub berdinding nipis dengan teras busa adalah satu kaedah yang biasa digunakan untuk menghasilkan prestasi penyerapan tenaga yang dikehendaki dan menstabilkan tindak balas remuk tiub berdinding nipis di bawah bebanan hentaman. Busa *auxetic* sebagai kelas baru bahan bersel, baru-baru ini telah mendapat populariti di kalangan komuniti penyelidikan disebabkan oleh sifat-sifat mekanikal yang dipertingkatkan. Walaupun begitu, maklumat reka bentuk ke atas prestasi penyerapan bagi tiub terisi dengan busa *auxetic* adalah amat terhad. Tujuan kajian ini adalah untuk menilai tindak balas remuk, kapasiti penyerapan tenaga dan kelakuan ubahbentuk bagi tiub berbentuk segi empat sama dan bulat terisi dengan busa *auxetic* di bawah keadaan bebanan kuasi-statik dan dinamik. Sebagai perbandingan, prestasi penyerapan tenaga tiub kosong dan tiub terisi dengan busa konvensional telah juga diperiksa secara eksperimen dan numerik terhadap mod ubah bentuk dan tindak balas beban-anjakan. Semua spesimen tiub telah diremukkan pada kadar bebanan tetap iaitu 3 mm/min bagi bebanan kuasi-statik dan pada halaju awal hentaman iaitu 5 m/s bagi bebanan dinamik. Untuk menyiasat pengaruh parameter-parameter tiub yang berkesan seperti ketebalan dinding, diameter, lebar dan ketinggian, satu siri kajian parametrik telah dijalankan dengan menggunakan model unsur terhingga (FE) yang telah disahkan. Penemuan awal menunjukkan bahawa kedua-dua tiub berbentuk segi empat sama dan bulat terisi dengan busa *auxetic* adalah lebih baik daripada tiub yang kosong dan tiub yang terisi dengan busa konvensional dari segi kapasiti penyerapan tenaga tanpa peningkatan beban puncak awal yang ketara. Dari penemuan awal dan potensi terbaik busa *auxetic* sebagai teras, satu teknik fabrikasi baru dinamakan Kaedah Kuasi Pemampatan Tri-paksi (QTCM) telah dibangunkan untuk menghasilkan busa *auxetic* dengan nisbah Poisson negatif maksimum yang boleh dicapai. Busa *auxetic* yang dihasilkan dengan *re-entrancy* optimum kemudiannya telah diperkenalkan sebagai teras untuk tiub. Selain daripada itu, kapasiti penyerapan tenaga bagi tiub terisi dengan busa *auxetic* telah ditentukan secara eksperimen dengan nisbah Poisson busa berjulat dari -0.13 hingga -0.32. Keputusan menunjukkan bahawa tenaga yang diserap oleh tiub segi empat sama dan bulat yang terisi dengan busa *auxetic* yang dibebani secara dinamik adalah masing-masing kira-kira 34.7% dan 22% lebih tinggi daripada tiub segi empat sama dan bulat yang terisi dengan busa konvensional. Ini adalah berfaedah secara praktikalnya apabila tenaga kinetik yang lebih tinggi perlu diserap untuk mengurangkan daya hentaman yang dipindahkan kepada ruang penghuni. Tambahan lagi, ianya jelas bahawa peningkatan tahap *auxeticity* bagi pengisi busa dapat meningkatkan prestasi tiub terisi di bawah kedua-dua keadaan bebanan kuasi-statik dan dinamik. Secara keseluruhannya, hasil utama tesis ini adalah satu garis panduan reka bentuk untuk penggunaan busa *auxetic* sebagai teras bagi peranti penyerapan tenaga yang mana beban hentaman adalah dijangkakan.

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LIST OF ABBREVIATIONS

AFFCT	-	Auxetic Foam-Filled Circular Tube
AFFT	-	Auxetic Foam-Filled Tube
CCF35	-	Conventional polymeric Closed-cell Foam; density 35 kg/m^3
CCF45	-	Conventional polymeric Closed-cell Foam; density 45 kg/m^3
CFE	-	Crush Force Efficiency
CFFCT	-	Conventional Foam-Filled Circular Tube
CFFT	-	Conventional Foam-Filled Tube
CL	-	Crushing Level
CON	-	Conventional foam
EA	-	Energy Absorption
ECT	-	Empty Circular Tube
ES	-	Element Size
ET	-	Empty Tube
FE	-	Finite Element
FEA	-	Finite Element Analysis
H	-	Hardness
IPL	-	Inward Penetration Length
L_{cr}	-	Critical length
LVDT	-	Linear Variable Displacement Transducer
MACS	-	Maximum Allowable Compressive Strain
MCF	-	Mean Crushing Force
MCL	-	Mean Crushing Load
NPR	-	Negative Poisson's Ratio
P_{max}	-	Initial Peak Load
PPI	-	Pores Per Inch
PPR	-	Positive Poisson's Ratio
P_s	-	Second Peak Load
QTCM	-	Quasi Tri-axial Compression Method
SDP	-	Starting Densification Point
SEA	-	Specific Energy Absorption

TL	-	Tube length
UTM	-	Universal Testing Machine
VCR	-	Volumetric Compression Ratio

LIST OF SYMBOLS

d	-	Diameter
d_0	-	Initial diameter
E	-	Young's modulus
ε	-	Strain
ε_{Axial}	-	Axial strain
ε_{Eng}	-	Engineering strain
ε_f	-	Fracture strain
$\varepsilon_{Lateral}$	-	Lateral strain
E_p	-	Plateau modulus
ε_{True}	-	True strain
F	-	Crushing force
h	-	Height
h_0	-	Initial height
I	-	Second moment inertia
m	-	Mass
n	-	Rotational stiffness
P_{cr}	-	Critical load
t	-	Thickness
t_0	-	Initial thickness
V	-	volume
V_0	-	Initial volume
w	-	Width
w_0	-	Initial width
δ	-	Crushing length
v	-	Poisson's ratio
ρ	-	Density
σ_{el}	-	Elastic collapse stress
σ_{el}	-	Elastic collapse stress
σ_{Eng}	-	Engineering stress
σ_{pl}	-	Plastic collapse stress

σ_{True}	-	True stress
σ_u	-	Ultimate tensile stress
σ_y	-	Initial yield stress
σ_{ys}	-	Yield stress

CHAPTER 1

INTRODUCTION

1.1 Background of Research

Increased interest in vehicle safety and crashworthiness has led to considerable investigations on energy absorption capability, crush response, and progressive collapse mode of energy absorbing devices from experimental, analytical and numerical points of view [1-3]. Thin-walled tubular structures as an effective energy absorbing devices have been impressively considered in structural impact applications for mitigating adverse effect of impact with controllable deformation. Therefore, thin-walled tubes have been extensively utilized in automobile industry since they are excellent at dissipating kinetic energy by progressive plastic deformation when subjected to different loading conditions. For instance, as indicated in Figure 1.1, crash boxes in automobile chassis are used for protecting the vehicle's structure and the occupants in the event of impact.

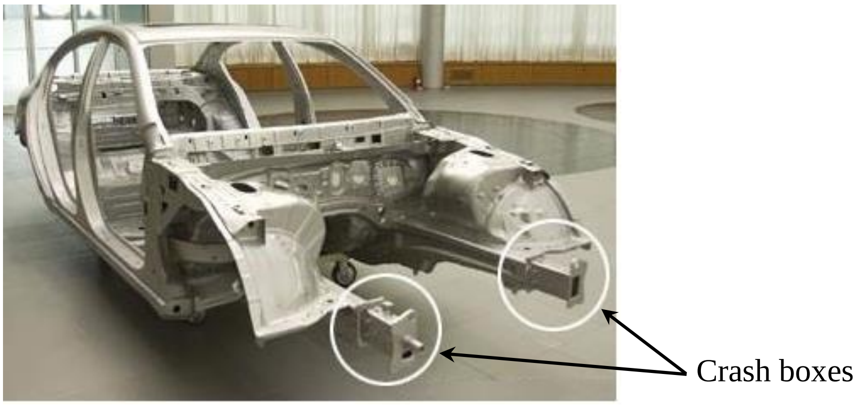


Figure 1.1 Crash boxes as an energy absorbing system [4]

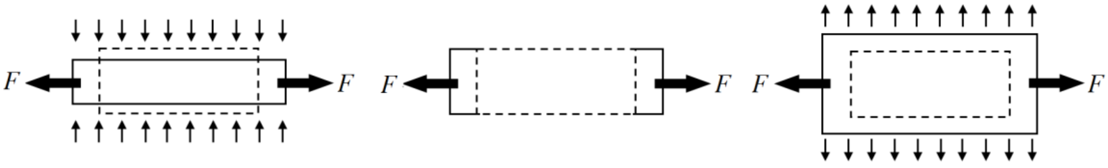
In general, principal factors like structural geometry, materials and loading conditions influence energy absorption capability of thin-walled structures remarkably. Hence, some beneficial numerical and experimental studies have been conducted to determine crashworthy characteristic of thin-walled tubes of various cross-sections under different loading conditions [5-7].

For many decades, progressive collapse mechanism and folding deformation of thin-walled tubes of various cross-sections have been widely investigated to figure out which cross-section could provide optimum crashworthiness performance [8, 9]. Crushing behavior and deformation modes of circular, rectangular, square, triangular, pyramidal, hexagonal and conical tubes under compressive axial loading were studied. Results of a study carried out by Nia and Parsapour [7], indicated that the cylindrical and triangular tubes exhibit the highest and lowest energy absorption capacity under compressive axial loading respectively.

Despite all modifications done to enhance crashworthiness efficiency of thin-walled structures, crush analysis and crashworthy response of foam-filled thin-walled tubes demonstrate grater energy dissipation, higher collapse resistance and fewer tendency to global bending than empty tubes [2, 10, 11]. Hence, crush response analysis of foam-filled tubes when loaded statically and dynamically has received increased attention in the literature [12, 13]. Accordingly, metallic and non-metallic foams have drawn extensive attention as fillers due to their good energy dissipation performance (since they can withstand large deformation when the load is kept constant). In an investigation on the crush and energy absorption responses of foam-filled extruded aluminum square tube under dynamic and quasi-static axial loading, Hanssen et al. [14] observed that introducing foam filler causes two changes in the crushing mode which are: increase in the number of fold and shorter fold length. Asavavisithchai et al. [15] compared energy absorption capability of foam-filled and empty circular tubes of different length when subjected to static axial load. They also investigated the energy absorbed by foam-filed tube, foam and empty tube individually. The results reveal that due to interaction effect, the sum of the absorbed energy of foam and empty tube is less than the absorbed energy by foam-filled tube. In addition, existence of foam in the tube structure alters the diamond mode of empty tube to concertina mode. Recently, Othman et al. [16] found that introducing polymeric foam into the composite pultruded square tube enhances specific energy absorption and crush force efficiency of pultruded tubes when subjected to quasi-static axial crushing. In a numerical parametric study, Ahmad and Thambiratnam [17, 18] found that inserting foam filler inside a conical tube may improve the collapse mode and crushing stability of a structure, resulting in greater crashworthiness performance under both oblique and axial loadings in the dynamic and quasi-static loading cases.

In general, the density of foam filler is the most effective factor that controls deformation mode and crush response behavior of foam-filled tube subjected to impact loading. In other words, increasing the density of foam promotes energy absorption capability of foam-filled tubes [19, 20]. However, very high density of foam filler may cause many undesirable crushing characteristics such as global Euler buckling, premature tensile rupture and low weight effectiveness which greatly decrease the energy absorption capacity of filled structures [10, 21]. Reid et al. [10] observed that, global Euler buckling occurred when polymeric foam of density over 320 kg/m^3 was inserted into square tube. Onsalung et al. [20] conducted a comparative experimental investigation on crush analysis of square tube filled with polymeric foam with densities 200 kg/m^3 and 300 kg/m^3, and discovered that specific energy absorption of filled tube is great when foam density 200 kg/m^3 is used.

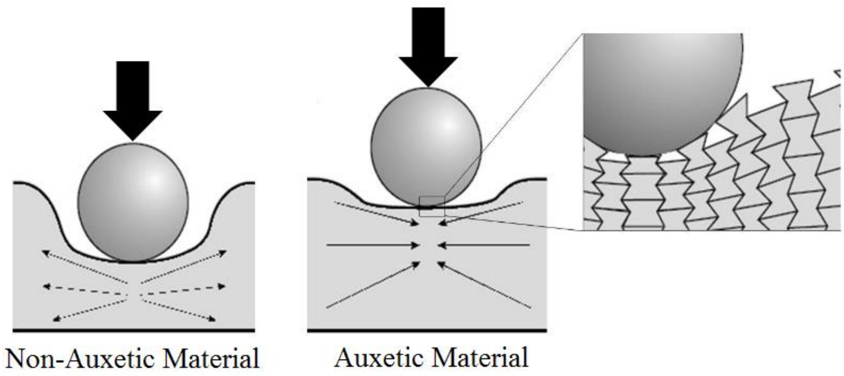
Most foam materials inserted in the tubes have a level of capacity to absorb energy. One of the most common specifications is to have positive Poisson's ratio (PPR) or zero Poisson's ratio (ZPR). It is worth noting that the shearing effect is nearly zero for foam materials with ZPR. In recent decade, a special interest has been shown in invention of foams with negative Poisson's ratio (NPR). Such foam materials that exhibit NPR are termed auxetic [22, 23]. Auxetic materials show an opposite behavior in which lateral expansion occurs during the longitudinal stretch and vice versa [24]. Figure 1.2 demonstrates the schematic deformation of material with PPR, ZPR and NPR under tensile strain.



(a) (b) (c)

Figure 1.2 Schematic behavior of material with (a) PPR, (b) ZPR and (c) NPR [25]

The pioneer study on engineering mechanics of NPR was published by Love [26], who presented a material with Poisson's ratio of −0.14 in two-dimensional (2D) plane. A preliminary work on the fabrication of re-entrant structure from a thermoplastic open cell foam was carried out by Lakes [22], who proposed two different fabrication methods for polymeric and metallic foams in details. The NPR property of auxetic materials offers several advantages such as enhancement of stiffness, energy dissipation, and indentation resistance (Figure 1.3) [25, 27, 28]. An improvement in these properties confers a great potential on the auxetic material to be used in a broad range of applications. The field of auxetic materials in science and engineering applications was practically initiated when the first NPR polyethylene foam was fabricated [29].



(a) (b)

Figure 1.3 Schematic deformation profile (indentation resistance) of (a) non-auxetic and (b) auxetic materials [25]

The classical fabrication process of polymeric auxetic foams includes the following steps: tri-axially compressing of conventional foam, heating the compressed foam then cooling or relaxation operations [30]. Lakes [22] converted a polymeric open-cell foam into an auxetic one by applying one-stage compression to protrude the ribs of each cell inward. The previous process is then followed by heating the foam slightly above its softening temperature to produce re-entrant structures. However, this method has few drawbacks such as severe surface wrinkling of foam and instability in the re-entrant structure. In certain cases, the foam reverts back to the original structure after a long while [30]. Meanwhile, the auxeticity procedure proposed by Lake [22] has been applied by several researchers though with numerous modifications. For instance, mold lubrication and the use of wires inside the mold for pulling the foam instead of pushing have been suggested to obviate the wrinkling problem [31]. Another way of solving the problem of wrinkles is applying the volumetric compression through several steps to obtain more homogeneous auxetic structures [30].

The use of compressed carbon dioxide [32] to modify the auxeticity process and application of solvents [33] as alternative to the heating stage have been suggested. In addition, replacing the rigid mold with a vacuum bag has also been reported in recent years [34]. Although the conversion process is carried out considering the above-mentioned combination, the modality of either compression or heating process (and/or solvent or carbon dioxide) has a significant impact on the re-entrant structure and mechanical properties of the produced auxetic foams.

1.2 Problem Statement

One of the most important goals of designing an energy absorbing device is to enable maximum energy absorption while the mass is minimal. Hence, cellular materials like foams could be utilized as effective core materials for thin-walled structures to attain a lightweight design [14, 31]. This is due to great energy absorption performance of foam materials as they can endure large deformation at almost constant load. Due to the importance of understanding the crushing characteristics of foam-filled tubes in the field of structural collapse and crashworthy design, a considerable amount of literature has been published on crush analysis of foam-filled thin-walled tubes [15, 17, 35].

During the past 40 years, altering the density of foam fillers were considered as a variable parameter in crashworthiness analysis of foam-filled tubular structures [10, 20]. Variations in the foam density directly affect Young's modulus, plateau stress and most other mechanical properties of foam material than Poisson's ratio. Meanwhile, the effect of foam Poisson's ratio has not been investigated in crush analysis of foam-filled tubular structures as an influencing parameter in determining mechanical deformation and crashworthiness performance of filled structures.

Regarding crush behavior, research information on using auxetic foam with NPR inside the thin-walled tubular structure as an absorber is still limited and sparse, notwithstanding their great potential to be an effective energy absorber.

Despite all modifications done in the auxeticity process, it is obvious that the overall procedure has remained the same, i.e., a volumetric compression of the foam followed by heating and cooling processes. Most established studies in the field of fabrication process concentrate on the heating operation or alternative ways of retaining the primary value of volumetric compression ratio of the foam and minimizing the problem of the foam reverting back to its original size. Meanwhile, the volumetric compression technique suggested by Lakes [22] has not been altered significantly except for the technique proposed by Chan and Evans [30]. The latter study adopted multi-stages volumetric compression ratio technique instead of a single-stage procedure. However, the determined starting densification point (SDP) in one direction was used for the other directions in the compression process. Thus, the wrinkles and creases of the foam surface were minimized but not removed completely. Therefore, more modifications are needed as the mentioned problems -foam instability and surface creasing and wrinkling- still exist. Furthermore, there is no published research on the determination of maximum allowable volumetric compression ratio as an influencing factor in converting process which determines auxeticity level of fabricated foam.

1.3 Research Objectives

The primary objective of this research is to evaluate the crush response and energy absorption performance of auxetic foam-filled tubes when subjected to compressive loading. Owing to the great potential of auxetic foam materials as a filler of thin-wall structures in energy absorption applications, an effort was made to improve the quality of the auxetic foam by employing a novel multi-stage compression methodology. Consequently, an optimum densification point for producing optimized auxetic foam in each of the three directions (x, y, z) was determined by a method called Quasi Tri-axial Compression Method (QTCM). Furthermore, the process of determining heating time was also modified in order to promote long-term stability of fabricated foam with the maximum stress relaxation. This research provides design information on impact behavior and crashworthiness performance of auxetic foam-filled tubes under quasi-static and dynamic loading to facilitate their application in energy absorbing systems.

The specific objectives of this research are briefly outlined as follows;

i) To determine densification points required for producing an optimum auxetic foam.

ii) To evaluate the influence of foam re-entrancy on energy absorption capacity and crush response of auxetic foam-filled tubes under quasi-static and dynamic axial loadings.

iii) To establish the influence of geometrical parameters on the energy absorption performance and deformation modes of auxetic foam-filled tubes.

1.4 Research Scopes

The scopes and limitations of this research are as follows.

(a) For fabricating auxetic foam, polyurethane (PU) foam materials with densities of 35 kg/m^3 and 45 kg/m^3 were considered due to their availability, accessibility and affordability.

(b) Square and circular thin-walled tubes were fabricated considering the following dimensions: thickness of 0.8 mm, outer width 26 mm and heights 50 and 60 mm for the square tube and thickness of 1 mm, outer diameter of 38 mm and height of 80 mm for the circular tubes.

(c) Tensile tests on aluminum tubes were conducted in accordance with ASTM E8M at a loading rate of 1mm/min.

(d) Tensile and compression tests on conventional and fabricated auxetic foams were performed at a loading speed of 1 mm/min in accordance to ASTM D3574-95 standard.

(e) Foam Poisson’s ratio was determined under compressive strain. Linear Variable Displacement Transducer (LVDT) was utilized to determine the lateral strain of polymeric foam under axial compressive load.

(f) Measuring the lateral strain of polymeric foam under compressive strain and determining foam Poisson’s ratio using Linear Variable Displacement Transducer (LVDT).

(g) Quasi-static axial crushing tests on the auxetic foam-filled tubes were conducted at a loading rate of 3 mm/min and 60% of original tube length as crushing length.

(h) Drop weight impact tests on the filled tube specimens was performed at an impact speed of 5 m/s.

(i) The auxetic foam-filled tubes under quasi-static axial loading was modeled using explicit nonlinear finite element commercial code LS-DYNA.

(j) The FE models for empty tube, conventional foam-filled tube and auxetic foam-filled tube were validated using the experimental test results obtained in quasi-static loading.

(k) The influence of effective tube parameters like wall thickness, height, width/diameter and slenderness ratio on energy absorption performance of empty tube, conventional and auxetic foam-filled tubes was evaluated.

1.5 Significance of Research

The present study has generated new design information on the energy absorption performance and crush response of auxetic foam-filled tubes subjected to compressive axial loading conditions. It has also established the effects of material and geometrical parameters such as foam density, foam Poisson's ratio, tube height, wall thickness, tube diameter and tube width on the energy absorption capacity of auxetic foam-filled tubes which enable efficient design of auxetic foam-filled tubes (square and circular cross-sections) as energy absorbing devices.

Practically, information obtained from this study can be employed to develop design guidelines for the use of auxetic foam-filled tubes as efficient energy absorbers, like vehicle protective structures. This will lead to an increase in the level of safety to the occupants of vehicles.

At present, the suggested approach for fabricating auxetic foam with maximum achievable re-entrancy is still limited and sparse. Hence, the proposed Quasi Tri-axial Compression Method (QTCM) can be used to fabricate auxetic foam with maximum auxeticity level. Moreover, by applying this novel methodology, long-term stability was observed for the fabricated auxetic foam due to attainment of maximum stress relaxation.

The auxetic foams developed in this study could potentially be used in numerous applications owing to their enhanced mechanical behavior compared to the conventional ones. From energy absorption point of view, the auxetic foam showed great potential to be used as an energy absorbing device in structural impact applications not limited to vehicular structures.

1.6 Outline of the Thesis

This thesis entails seven chapters which are arranged thus.

Chapter 2 provides a detailed literature review of the work related to the objectives and scopes of this thesis. The fundamental concept of structural crashworthiness, energy absorption characteristics, impact engineering, thin-walled structures, cellular materials and auxetic foam are summarized in this chapter. Furthermore, an investigation into the fabrication process of polymeric auxetic foam and experimental testing of such materials is also discussed.

Chapter 3 details the research methodology used in this study. The detailed description of material testing, quasi-static and dynamic test conditions are given. Moreover, the development of the FE model for conventional and auxetic foam-filled tubes (square and circular cross-sections) under quasi-static axial loading is explained in this chapter.

Chapter 4 describes the initial study on crush response and energy absorption capability of auxetic foam-filled square tube under quasi-static axial loading conditions.

Chapter 5 elaborates the proposed methodology used for producing the auxetic foam with the maximum achievable negative Poisson's ratio.

Chapter 6 discusses the influence of Poisson's ratio of auxetic foam core on crushing characteristic and energy absorption performance of auxetic foam-filled tubes under quasi-static and dynamic loadings. The interaction effect between the fabricated auxetic foam and tube walls is also determined. In addition, a parametric study of the energy absorption response of auxetic foam filled tube under quasi-static loading is presented.

Chapter 7 summarizes the main conclusion and contribution of this study and the future work is eventually proposed.

REFERENCES

1. Abramowicz W, Jones N. Dynamic axial crushing of square tubes. International Journal of Impact Engineering. 1984;2(2):179-208.
2. Santosa SP, Wierzbicki T, Hanssen AG, Langseth M. Experimental and numerical studies of foam-filled sections. International Journal of Impact Engineering. 2000;24(5):509-34.
3. Langseth M, Hopperstad O, Hanssen A. Crash behaviour of thin-walled aluminium members. Thin-walled structures. 1998;32(1-3):127-50.
4. Kusyairi I, Choiron MA, Irawan YS, Himawan HM. Effects of Origami Pattern Crash Box and Rectangular Pattern Crash Box on The Modelling Of MPV Car Structure on Deformation. Journal of Energy, Mechanical, Material and Manufacturing Engineering. 2018;3(2):61-8.
5. Zhang X, Wen Z, Zhang H. Axial crushing and optimal design of square tubes with graded thickness. Thin-Walled Structures. 2014;84:263-74.
6. Reyes A, Langseth M, Hopperstad OS. Square aluminum tubes subjected to oblique loading. International Journal of Impact Engineering. 2003;28(10):1077-106.
7. Nia AA, Parsapour M. Comparative analysis of energy absorption capacity of simple and multi-cell thin-walled tubes with triangular, square, hexagonal and octagonal sections. Thin-Walled Structures. 2014;74:155-65.
8. Fan Z, Lu G, Liu K. Quasi-static axial compression of thin-walled tubes with different cross-sectional shapes. Engineering Structures. 2013;55:80-9.
9. Hosseinipour S, Daneshi G. Energy absorbtion and mean crushing load of thin-walled grooved tubes under axial compression. Thin-walled structures. 2003;41(1):31-46.
10. Reid SR, Reddy T, Gray M. Static and dynamic axial crushing of foam-filled sheet metal tubes. International Journal of Mechanical Sciences. 1986;28(5):295-322.
11. Reddy T, Wall R. Axial compression of foam-filled thin-walled circular tubes. International Journal of Impact Engineering. 1988;7(2):151-66.
12. Li Z, Chen R, Lu F. Comparative analysis of crashworthiness of empty and foam-filled thin-walled tubes. Thin-Walled Structures. 2018;124:343-9.
13. Dirgantara T, Jusuf A, Kurniati EO, Gunawan L, Putra IS. Crashworthiness analysis of foam–filled square column considering strain rate effect of the foam. Thin-Walled Structures. 2018;129:365-80.
14. Hanssen AG, Langseth M, Hopperstad OS. Static and dynamic crushing of square aluminium extrusions with aluminium foam filler. International Journal of Impact Engineering. 2000;24(4):347-83.

15. Asavavisithchai S, Slater D, Kennedy A. Effect of tube length on the bucking mode and energy absorption of Al foam-filled tubes. Journal of materials science. 2004;39(24):7395-6.

16. Othman A, Abdullah S, Ariffin A, Mohamed N. Investigating the quasi-static axial crushing behavior of polymeric foam-filled composite pultrusion square tubes. Materials & Design. 2014;63:446-59.

17. Ahmad Z, Thambiratnam D. Crushing response of foam-filled conical tubes under quasi-static axial loading. Materials & design. 2009;30(7):2393-403.

18. Ahmad Z, Thambiratnam D, Tan A. Dynamic energy absorption characteristics of foam-filled conical tubes under oblique impact loading. International Journal of Impact Engineering. 2010;37(5):475-88.

19. Mirfendereski L, Salimi M, Ziaei-Rad S. Parametric study and numerical analysis of empty and foam-filled thin-walled tubes under static and dynamic loadings. International Journal of Mechanical Sciences. 2008;50(6):1042-57.

20. Onsalung N, Thinvongpituk C, Painthong K. The influence of foam density on specific energy absorption of rectangular steel tubes. Energy Research Journal, 1 (2). 2010:135-40.

21. Lu G, Yu T. Energy absorption of structures and materials: Elsevier; 2003.

22. Lakes R. Foam structures with a negative Poisson's ratio. Science. 1987;235:1038-41.

23. Evans KE, Nkansah M, Hutchinson I, Rogers S. Molecular network design. Nature. 1991;353(6340):124.

24. Prawoto Y. Seeing auxetic materials from the mechanics point of view: a structural review on the negative Poisson’s ratio. Computational Materials Science. 2012;58:140-53.

25. Evans KE, Alderson A. Auxetic materials: functional materials and structures from lateral thinking! Advanced materials. 2000;12(9):617-28.

26. Love AEH. A treatise on the mathematical theory of elasticity: Cambridge university press; 2013.

27. Bianchi M, Scarpa FL, Smith CW. Stiffness and energy dissipation in polyurethane auxetic foams. Journal of Materials Science. 2008;43(17):5851-60.

28. Choi J, Lakes R. Non-linear properties of polymer cellular materials with a negative Poisson's ratio. Journal of Materials Science. 1992;27(17):4678-84.

29. Duncan O, Shepherd T, Moroney C, Foster L, Venkatraman P, Winwood K, et al. Review of auxetic materials for sports applications: Expanding options in comfort and protection. Applied Sciences. 2018;8(6):941.

30. Chan N, Evans K. Fabrication methods for auxetic foams. Journal of Materials Science. 1997;32(22):5945-53.

31. Scarpa F, Pastorino P, Garelli A, Patsias S, Ruzzene M. Auxetic compliant flexible PU foams: static and dynamic properties. physica status solidi (b). 2005;242(3):681-94.

32. Li Y, Zeng C. Room-temperature, near-instantaneous fabrication of auxetic materials with constant Poisson's ratio over large deformation. Advanced Materials. 2016;28(14):2822-6.

33. Grima JN, Attard D, Gatt R, Cassar RN. A Novel Process for the Manufacture of Auxetic Foams and for Their re-Conversion to Conventional Form. Advanced Engineering Materials. 2009;11(7):533-5.

34. Bianchi M, Scarpa F, Banse M, Smith C. Novel generation of auxetic open cell foams for curved and arbitrary shapes. Acta Materialia. 2011;59(2):686-91.

35. Duarte I, Krstulović-Opara L, Dias-de-Oliveira J, Vesenjak M. Axial crush performance of polymer-aluminium alloy hybrid foam filled tubes. Thin-Walled Structures. 2019;138:124-36.

36. Ahmad Z. Impact and energy absorption of empty and foam-filled conical tubes: Queensland University of Technology; 2009.

37. Jones N. Structural impact: Cambridge university press; 2011.

38. Ambrósio JA, Pereira MFS, da Silva FP. Crashworthiness of transportation systems: structural impact and occupant protection: Springer Science & Business Media; 2012.

39. Deb A, Mahendrakumar M, Chavan C, Karve J, Blankenburg D, Storen S. Design of an aluminium-based vehicle platform for front impact safety. International journal of impact engineering. 2004;30(8-9):1055-79.

40. Brown J. Introduction to the basic principles of crashworthiness. Bedfordshire: Cranfield University. 2002.

41. Sun G, Liu T, Huang X, Zheng G, Li Q. Topological configuration analysis and design for foam filled multi-cell tubes. Engineering Structures. 2018;155:235-50.

42. Liu W, Lin Z, Wang N, Deng X. Dynamic performances of thin-walled tubes with star-shaped cross section under axial impact. Thin-Walled Structures. 2016;100:25-37.

43. Hanssen AG, Langseth M, Hopperstad OS. Static and dynamic crushing of circular aluminium extrusions with aluminium foam filler. International Journal of Impact Engineering. 2000;24(5):475-507.

44. Eyvazian A, Habibi MK, Hamouda AM, Hedayati R. Axial crushing behavior and energy absorption efficiency of corrugated tubes. Materials & Design (1980-2015). 2014;54:1028-38.

45. Zarei H, Kröger M. Multiobjective crashworthiness optimization of circular aluminum tubes. Thin-walled structures. 2006;44(3):301-8.

46. Baroutaji A, Sajjia M, Olabi A-G. On the crashworthiness performance of thin-walled energy absorbers: recent advances and future developments. Thin-Walled Structures. 2017;118:137-63.

47. Witteman W. Improved vehicle crashworthiness design by control of the energy absorption for different collision situations. Ph D Thesis, University of Technology, Automotive Engineering and Product Design Technology, Eindhoven, The Netherlands. 1999.

48. Gan N, Yao S, Dong H, Xiong Y, Liu D, Pu D. Energy absorption characteristics of multi-frusta configurations under axial impact loading. Thin-Walled Structures. 2018;122:147-57.

49. Rahi A. Controlling energy absorption capacity of combined bitubular tubes under axial loading. Thin-Walled Structures. 2018;123:222-31.

50. Azarakhsh S, Ghamarian A. Collapse behavior of thin-walled conical tube clamped at both ends subjected to axial and oblique loads. Thin-Walled Structures. 2017;112:1-11.

51. Hussein RD, Ruan D, Lu G, Guillow S, Yoon JW. Crushing response of square aluminium tubes filled with polyurethane foam and aluminium honeycomb. Thin-Walled Structures. 2017;110:140-54.

52. Nia AA, Hamedani JH. Comparative analysis of energy absorption and deformations of thin walled tubes with various section geometries. Thin-Walled Structures. 2010;48(12):946-54.

53. Li G, Xu F, Sun G, Li Q. A comparative study on thin-walled structures with functionally graded thickness (FGT) and tapered tubes withstanding oblique impact loading. International Journal of Impact Engineering. 2015;77:68-83.

54. Zhang X, Zhang H. Static and dynamic bending collapse of thin-walled square beams with tube filler. International Journal of Impact Engineering. 2018;112:165-79.

55. Nia AA, Khodabakhsh H. The effect of radial distance of concentric thin-walled tubes on their energy absorption capability under axial dynamic and quasi-static loading. Thin-Walled Structures. 2015;93:188-97.

56. Karagiozova D, Jones N. Dynamic elastic–plastic buckling of circular cylindrical shells under axial impact. International Journal of Solids and Structures. 2000;37(14):2005-34.

57. Montazeri S, Elyasi M, Moradpour A. Investigating the energy absorption, SEA and crushing performance of holed and grooved thin-walled tubes under axial loading with different materials. Thin-Walled Structures. 2018;131:646-53.

58. Bai J, Meng G, Wu H, Zuo W. Bending collapse of dual rectangle thin-walled tubes for conceptual design. Thin-Walled Structures. 2019;135:185-95.

59. Reid S. Plastic deformation mechanisms in axially compressed metal tubes used as impact energy absorbers. International Journal of Mechanical Sciences. 1993;35(12):1035-52.

60. Hussein RD, Ruan D, Lu G, Sbarski I. Axial crushing behaviour of honeycomb-filled square carbon fibre reinforced plastic (CFRP) tubes. Composite Structures. 2016;140:166-79.

61. Yin H, Wen G, Hou S, Chen K. Crushing analysis and multiobjective crashworthiness optimization of honeycomb-filled single and bitubular polygonal tubes. Materials & Design. 2011;32(8-9):4449-60.

62. Li Z, Lu F. Bending resistance and energy-absorbing effectiveness of empty and foam-filled thin-walled tubes. Journal of Reinforced Plastics and Composites. 2015;34(9):761-8.

63. Linul E, Movahedi N, Marsavina L. On the lateral compressive behavior of empty and ex-situ aluminum foam-filled tubes at high temperature. Materials. 2018;11(4):554.

64. Aktay L, Toksoy AK, Güden M. Quasi-static axial crushing of extruded polystyrene foam-filled thin-walled aluminum tubes: experimental and numerical analysis. Materials & design. 2006;27(7):556-65.

65. Tarlochan F, Samer F, Hamouda A, Ramesh S, Khalid K. Design of thin wall structures for energy absorption applications: enhancement of crashworthiness due to axial and oblique impact forces. Thin-Walled Structures. 2013;71:7-17.

66. Fan Z, Lu G, Yu T, Liu K. Axial crushing of triangular tubes. International Journal of Applied Mechanics. 2013;5(01):1350008.

67. Abramowicz W, Jones N. Dynamic axial crushing of circular tubes. International Journal of Impact Engineering. 1984;2(3):263-81.

68. Abramowicz W, Jones N. Dynamic progressive buckling of circular and square tubes. International Journal of Impact Engineering. 1986;4(4):243-70.

69. Al Galib D, Limam A. Experimental and numerical investigation of static and dynamic axial crushing of circular aluminum tubes. Thin-Walled Structures. 2004;42(8):1103-37.

70. Abramowicz W. Thin-walled structures as impact energy absorbers. Thin-Walled Structures. 2003;41(2-3):91-107.

71. Guillow S, Lu G, Grzebieta R. Quasi-static axial compression of thin-walled circular aluminium tubes. International Journal of Mechanical Sciences. 2001;43(9):2103-23.

72. Abramowicz W, Jones N. Transition from initial global bending to progressive buckling of tubes loaded statically and dynamically. International Journal of Impact Engineering. 1997;19(5-6):415-37.

73. Jensen Ø, Langseth M, Hopperstad O. Transition between progressive and global buckling of aluminium extrusions. WIT Transactions on The Built Environment. 2002;63.

74. Karagiozova D, Alves Ml. Transition from progressive buckling to global bending of circular shells under axial impact—Part I: Experimental and numerical observations. International Journal of Solids and Structures. 2004;41(5-6):1565-80.

75. Xu S, Ruan D, Lu G. Strength enhancement of aluminium foams and honeycombs by entrapped air under dynamic loadings. International Journal of Impact Engineering. 2014;74:120-5.

76. Veale PJ. Investigation of the behavior of open cell aluminum foam. 2010.

77. Chan N, Evans K. Microscopic examination of the microstructure and deformation of conventional and auxetic foams. Journal of Materials Science. 1997;32(21):5725-36.

78. Gibson LJ, Ashby MF. Cellular solids: structure and properties: Cambridge university press; 1999.

79. Warren W, Kraynik A. Foam mechanics: the linear elastic response of two-dimensional spatially periodic cellular materials. Mechanics of Materials. 1987;6(1):27-37.

80. Timoshenko SP, Gere JM. Theory of elastic stability. 1961. McGrawHill-Kogakusha Ltd, Tokyo. 1961:109.

81. De Vries D. Characterization of polymeric foams. Eindhoven University of Technology. 2009.

82. Ghamarian A, Zarei H, Farsi M, Ariaeifar N. Experimental and numerical crashworthiness investigation of the empty and foam-filled conical tube with shallow spherical caps. Strain. 2013;49(3):199-211.

83. Gao Q, Wang L, Wang Y, Wang C. Crushing analysis and multiobjective crashworthiness optimization of foam-filled ellipse tubes under oblique impact loading. Thin-Walled Structures. 2016;100:105-12.

84. Reddy T, Al-Hassani S. Axial crushing of wood-filled square metal tubes. International journal of mechanical sciences. 1993;35(3-4):231-46.

85. Gameiro C, Cirne J. Dynamic axial crushing of short to long circular aluminium tubes with agglomerate cork filler. International Journal of Mechanical Sciences. 2007;49(9):1029-37.

86. Tankara D, Moradi R, Tay YY, Lankarani HM, editors. Energy absorption characteristics of a thin-walled tube filled with carbon nano polyurethane foam and application in car bumper. ASME 2014 International Mechanical Engineering Congress and Exposition; 2014: American Society of Mechanical Engineers.

87. Toksoy AK, Güden M. The strengthening effect of polystyrene foam filling in aluminum thin-walled cylindrical tubes. Thin-walled structures. 2005;43(2):333-50.

88. Børvik T, Hopperstad OS, Reyes A, Langseth M, Solomos G, Dyngeland T. Empty and foam-filled circular aluminium tubes subjected to axial and oblique quasistatic loading. International Journal of Crashworthiness. 2003;8(5):481-94.

89. Gameiro CP, Cirne J. Dynamic axial crushing of short to long circular aluminium tubes with agglomerate cork filler. International Journal of Mechanical Sciences. 2007;49(9):1029-37.

90. Yan L, Chouw N, Jayaraman K. Effect of triggering and polyurethane foam-filler on axial crushing of natural flax/epoxy composite tubes. Materials & Design (1980-2015). 2014;56:528-41.

91. Seitzberger M, Rammerstorfer FG, Gradinger R, Degischer H, Blaimschein M, Walch C. Experimental studies on the quasi-static axial crushing of steel columns filled with aluminium foam. International Journal of Solids and Structures. 2000;37(30):4125-47.

92. Zarei H, Kröger M. Optimization of the foam-filled aluminum tubes for crush box application. Thin-Walled Structures. 2008;46(2):214-21.

93. Santosa S, Wierzbicki T. Crash behavior of box columns filled with aluminum honeycomb or foam. Computers & Structures. 1998;68(4):343-67.

94. Young T. On passive strength and friction. Course of lectures on natural philosophy and themechanical arts: lecture. London: Taylor and Walton; 1807.

95. Xiong J, Gu D, Chen H, Dai D, Shi Q. Structural optimization of re-entrant negative Poisson's ratio structure fabricated by selective laser melting. Materials & Design. 2017;120:307-16.

96. Wang K, Chang Y-H, Chen Y, Zhang C, Wang B. Designable dual-material auxetic metamaterials using three-dimensional printing. Materials & Design. 2015;67:159-64.

97. Shokri Rad M, Prawoto Y, Ahmad Z. Analytical solution and finite element approach to the 3D re-entrant structures of auxetic materials. Mechanics of Materials. 2014;74(0):76-87.

98. Love A. A treatise on the mathematical theory of elasticity, Dover Publications. New York. 1944;1.

99. Gibson L, Ashby M, Schajer G, Robertson C, editors. The mechanics of two-dimensional cellular materials. Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences; 1982: The Royal Society.

100. Lakes R. Foam structures with a negative Poisson's ratio. Science. 1987;235(4792):1038-40.

101. Evans K, Nkansah M, Hutchinson I. Molecular network design. 1991.

102. Caddock B, Evans K. Microporous materials with negative Poisson's ratios. I. Microstructure and mechanical properties. Journal of Physics D: Applied Physics. 1989;22(12):1877.

103. Evans K, Caddock B. Microporous materials with negative Poisson's ratios. II. Mechanisms and interpretation. Journal of Physics D: Applied Physics. 1989;22(12):1883.

104. Anurag C, Harsha AS, Anvesh CK. Auxetic materials. Int J Trends Eng Technol. 2015;5(2):156-60.

105. Bianchi M, Scarpa F, Smith C. Shape memory behaviour in auxetic foams: mechanical properties. Acta Materialia. 2010;58(3):858-65.

106. Smith CW, Grima J, Evans K. A novel mechanism for generating auxetic behaviour in reticulated foams: missing rib foam model. Acta materialia. 2000;48(17):4349-56.

107. Cadamagnani F, Frontoni S, Bianchi M, Scarpa F. Compressive uniaxial properties of auxetic open cell PU based foams. physica status solidi (b). 2009;246(9):2118-23.

108. Friis E, Lakes R, Park J. Negative Poisson's ratio polymeric and metallic foams. Journal of Materials Science. 1988;23(12):4406-14.

109. Wang Y-C, Lakes R, Butenhoff A. Influence of cell size on re-entrant transformation of negative Poisson's ratio reticulated polyurethane foams. Cellular Polymers. 2001;20(6):373-85.

110. Rad MS. Auxetic Structures for Energy Absorption Applications: Universiti Teknologi Malaysia; 2015.

111. Bianchi M, Scarpa F, Smith C, Whittell GR. Physical and thermal effects on the shape memory behaviour of auxetic open cell foams. Journal of materials science. 2010;45(2):341.

112. Choi J, Lakes R. Non-linear properties of metallic cellular materials with a negative Poisson's ratio. Journal of Materials Science. 1992;27(19):5375-81.

113. Scarpa F, Ciffo L, Yates J. Dynamic properties of high structural integrity auxetic open cell foam. Smart Materials and Structures. 2003;13(1):49.

114. Alderson A, Rasburn J, Evans K. Mass transport properties of auxetic (negative Poisson's ratio) foams. physica status solidi (b). 2007;244(3):817-27.

115. Lakes R. No contractile obligations. Nature. 1992;358(6389):713.

116. Lakes R. Deformation mechanisms in negative Poisson's ratio materials: structural aspects. Journal of materials science. 1991;26(9):2287-92.

117. Rothenburg L, Berlin AA, Bathurst RJ. Microstructure of isotropic materials with negative Poisson's ratio. Nature. 1991;354(6353):470.

118. Bezazi A, Scarpa F. Tensile fatigue of conventional and negative Poisson's ratio open cell PU foams. International Journal of Fatigue. 2009;31(3):488-94.

119. Bezazi A, Scarpa F. Mechanical behaviour of conventional and negative Poisson's ratio thermoplastic polyurethane foams under compressive cyclic loading. International Journal of fatigue. 2007;29(5):922-30.

120. Scarpa F, Bullough W, Lumley P. Trends in acoustic properties of iron particle seeded auxetic polyurethane foam. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science. 2004;218(2):241-4.

121. Scarpa F, Smith F. Passive and MR fluid-coated auxetic PU foam–mechanical, acoustic, and electromagnetic properties. Journal of intelligent material systems and structures. 2004;15(12):973-9.

122. Grima JN. Auxetic metamaterials. Strasbourg, France. 2010.

123. Argatov II, Guinovart-Díaz R, Sabina FJ. On local indentation and impact compliance of isotropic auxetic materials from the continuum mechanics viewpoint. International Journal of Engineering Science. 2012;54:42-57.

124. Coenen V, Alderson K. Mechanisms of failure in the static indentation resistance of auxetic carbon fibre laminates. physica status solidi (b). 2011;248(1):66-72.

125. Scarpa F, Yates J, Ciffo L, Patsias S. Dynamic crushing of auxetic open-cell polyurethane foam. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science. 2002;216(12):1153-6.

126. Mir M, Ali MN, Sami J, Ansari U. Review of mechanics and applications of auxetic structures. Advances in Materials Science and Engineering. 2014;2014.

127. Alderson A, Alderson K. Expanding materials and applications: exploiting auxetic textiles. Technical textiles international. 2005;14(6):29-34.

128. Alderson A, Alderson K. Auxetic materials. Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering. 2007;221(4):565-75.

129. Avellaneda M, Swart PJ. Calculating the performance of 1–3 piezoelectric composites for hydrophone applications: an effective medium approach. The Journal of the Acoustical Society of America. 1998;103(3):1449-67.

130. Alderson A. A triumph of lateral thought. Chemistry & Industry. 1999;17:384-91.

131. Baughman RH, Shacklette JM, Zakhidov AA, Stafström S. Negative Poisson's ratios as a common feature of cubic metals. Nature. 1998;392(6674):362.

132. Testing AASf, Materials. Standard test methods for tension testing of metallic materials: ASTM international; 2009.

133. ASTM D. 3574—Standard Test Methods for Flexible Cellular Materials—Slab. Bonded, and Molded Urethane Foams. 2001.

134. Huber A, Gibson L. Anisotropy of foams. Journal of Materials Science. 1988;23(8):3031-40.

135. Hallquist J. LS-DYNA Theoretical Manual (Livermore, CA: Livermore Software Technology Corporation). 2006.

136. Boyer HE. Atlas of Stress--strain Curves. ASM International, Metals Park, Ohio 44073, USA, 1987 630. 1987.

137. Boresi AP, Schmidt RJ, Sidebottom OM. Advanced mechanics of materials: Wiley New York et al.; 1985.

138. Ling Y. Uniaxial true stress-strain after necking. AMP Journal of technology. 1996;5(1):37-48.

139. Zhang Z, Liu S, Tang Z. Comparisons of honeycomb sandwich and foam-filled cylindrical columns under axial crushing loads. Thin-Walled Structures. 2011;49(9):1071-9.

140. Hou S, Liu T, Zhang Z, Han X, Li Q. How does negative Poisson’s ratio of foam filler affect crashworthiness? Materials & Design. 2015;82:247-59.

141. Shah QH, Topa A. Modeling large deformation and failure of expanded polystyrene crushable foam using LS-DYNA. Modelling and Simulation in Engineering. 2014;2014:1.

142. Hanssen A, Hopperstad OS, Langseth M, Ilstad H. Validation of constitutive models applicable to aluminium foams. International journal of mechanical sciences. 2002;44(2):359-406.

143. Zangani D, Robinson M, Gibson A. Progressive failure of composite hollow sections with foam-filled corrugated sandwich walls. Applied Composite Materials. 2007;14(5-6):325-42.

144. Hallquist JO. LS-DYNA® Keyword User’s Manual Volume II Material Models. Livermore, California, USA. 2013.

145. Tarigopula V, Langseth M, Hopperstad OS, Clausen AH. Axial crushing of thin-walled high-strength steel sections. International Journal of Impact Engineering. 2006;32(5):847-82.

146. Reid J, Hiser N. Friction modelling between solid elements. International Journal of Crashworthiness. 2004;9(1):65-72.

147. Bala S. Contact modeling in LS-DYNA. Livermore Software Technology Corporation. 2001.

148. Baroutaji A. Energy absorption through the lateral collapse of thin-walled single and nested tubes: Dublin City University; 2014.

149. Hallquist JO. LS-DYNA keyword user's manual. Livermore Software Technology Corporation. 2007;970:299-800.

150. Barsotti M. Comparison of FEM and SPH for modeling a crushable foam aircraft arrestor bed. Aerospace Journal. 2012.

151. Wu J, Wang Y, Wan Y, Lei H, Yu F, Liu Y, et al. Processing and properties of rigid polyurethane foams based on bio-oils from microwave-assisted pyrolysis of corn stover. International Journal of Agricultural and Biological Engineering. 2009;2(1):40-50.

152. Kormin S, Rus A. Fabrication and characterization of polyurethane foam prepared from liquefied oil palm mesocarp fibre with renewable monomer made from waste cooking oil. Journal of Fundamental and Applied Sciences. 2018;10(2S):722-44.

153. Shokri Rad M, Ahmad Z. New approach for fabrication of auxetic foam and determination of Poisson's ratio. Applied Mechanics & Materials. 2014(695).

154. Lu R, Liu X, Chen S, Hu X, Liu L. Axial crashing analysis for tailor rolled square tubes with axially graded both wall thickness and material strength. Thin-Walled Structures. 2017;117:10-24.

155. Thirumal M, Khastgir D, Singha NK, Manjunath B, Naik Y. Effect of foam density on the properties of water blown rigid polyurethane foam. Journal of applied polymer science. 2008;108(3):1810-7.

156. Wu J-W, Sung W-F, Chu H-S. Thermal conductivity of polyurethane foams. International Journal of Heat and Mass Transfer. 1999;42(12):2211-7.

157. Spathis G, Niaounakis M, Kontou E, Apekis L, Pissis P, Christodoulides C. Morphological changes in segmented polyurethane elastomers by varying the NCO/OH ratio. Journal of applied polymer science. 1994;54(7):831-42.

158. Gogoi R, Niyogi UK, Alam MS, Mehra DS. Study of effect of NCO/OH molar ratio and molecular weight of polyol on the physico-mechanical properties of polyurethane plaster cast. World Applied Sciences Journal. 2013;21(2):276-83.

159. Kumar A, Gupta RK. Fundamentals of polymer engineering, revised and expanded: CRC Press; 2003.

160. Ouellet S, Cronin D, Worswick M. Compressive response of polymeric foams under quasi-static, medium and high strain rate conditions. Polymer testing. 2006;25(6):731-43.

161. Critchley R, Corni I, Wharton JA, Walsh FC, Wood RJ, Stokes KR. A review of the manufacture, mechanical properties and potential applications of auxetic foams. physica status solidi (b). 2013;250(10):1963-82.

LIST OF PUBLICATIONS

1. Mohsenizadeh, S., Alipour, R., Rad, M. S., Nejad, A. F., & Ahmad, Z. (2015). Crashworthiness assessment of auxetic foam-filled tube under quasi-static axial loading. *Materials & Design*, *88*, 258-268. (Q1-*IF* 4.525)

2. Mohsenizadeh, S., Ahmad, Z., Alipour, R., Majid, R, A., & Prawoto, Y. (2019). Quasi Tri-Axial Method for the Fabrication of Optimized Polyurethane Auxetic Foams. physica status solidi (b), 1800587. (Q3- *IF* 1.729)

3. Mohsenizadeh, S., Alipour, R., Ahmad, Z., & Alias, A. (2016). Influence of auxetic foam in quasi-static axial crushing. *International Journal of Materials Research*, *107*(10), 916-924. (Q3- *IF* 0.748)