UNIVERSITI PUTRA MALAYSIA

AUXETIC CELL STRUCTURE AS AN IMPACT ABSORBING MATERIAL IN BIO-COMPOSITE AERO HELMET

MOHD SAFFUAN BIN YAAKOB

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By

MOHD SAFFUAN BIN YAAKOB

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

November 2016

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DEDICATION

To Allah SWT, my beloved Parents, my dearest Wife, my precious son, my supportive Family and Friends.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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November 2016

Chair: Faizal Mustapha, PhD
Faculty: Engineering

This study is specifically concerned with the application of auxetic cell structures as an impact absorbing material. Despite the need of high energy absorption materials in safety application, limited research has been devoted to identify the potential of auxetic cell structures as an impact absorbing materials. An extensive literature review highlighted past research on auxetic cell structure and its limitation, especially as related to energy absorbed, fabrication process and application. The information gaps identified in the review became the basis of this study in creating an impact absorbing materials for bio-composite aero helmet interior. The main objective of this research is to design a new interior for bio-composite aero helmet comply to standards set by The Consumer Product Safety Commission of bike helmet standard. Experiments were conducted namely drop weight impact test and oblique impact test. The study follows ASTM D7136 / D7136M – 15 standards and European Standard; EN 1078. Comparison has been made between the Expanded Polystyrene (EPS), Polyurethane Foam, Auxetic Design 1 and Auxetic Design 2 to evaluate the energy absorbed in drop weight impact test. Experimental results showed that Auxetic Design 2 and Polyurethane Foam has shown a high absorbed energy thus been used as material for helmet interior. For oblique impact test, four sport cycling helmets being tested; Kabuto Helmet, Kenaf Helmet, Flax Helmet and Flax Helmet with Auxetic Interior. The study proved that flax helmet with auxetic interior has the lowest linear acceleration compared to other helmets tested. When used as interior materials, auxetic cell structure can potentially improve the safety factor in bio-composite aero helmet. Main findings revealed that auxetic cell structure proved to be the best alternative impact absorbing material compared to crushable foam, as helmet interior.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia Sebagai memenuhi keperluan untuk ijazah Master sains

APLIKASI STRUKTUR SEL AUXETIK SEBAGAI BAHAN MENYERAP HENTAKAN DI DALAM TOPI KELEDAR AERO BIO-KOMPOSIT

Oleh

MOHD SAFFUAN BIN YAAKOB

November 2016

Pengerusi: Faizal Mustapha, PhD
Fakulti: Kejuruteraan

Kajian ini adalah khusus berkenaan dengan penggunaan struktur sel auxetik sebagai bahan menyerap hentakan. Walaupun keperluan bahan-bahan penyerap tenaga yang tinggi dalam penggunaan keselamatan, penyelidikan terhad telah dikhaskan untuk mengenal pasti potensi struktur sel auxetic sebagai bahan menyerap hentakan. Satu kajian yang banyak menekankan penyelidikan masa lalu pada struktur sel auxetic dan batasan, khasnya apabila berkaitan dengan tenaga diserap, proses fabrikasi dan aplikasi. Jurang maklumat yang dikenal pasti dalam kajian semula itu menjadi asas kepada kajian ini dalam mewujudkan kesan menyerap bahan-bahan untuk dalaman topi keledar aero bio-komposit. Objektif utama kajian ini adalah untuk mereka bentuk dalaman yang baru untuk topi keledar aero bio-komposit bagi mematuhi piawaian yang ditetapkan oleh Suruhanjaya Keselamatan Produk Pengguna bagi standard topi keledar basikal. Eksperimen telah dijalankan iaitu ujian penurunan berat badan dan kesan ujian kesan serong. Kajian berikut ASTM D7136 / D7136M - 15 standard dan Standard Eropah; EN 1078. Perbandingan telah dibuat antara 'Expanded Polystyrene' (EPS), 'Polyurethane Foam', 'Auxetic Design 1' dan 'Auxetic Design 2' untuk menilai tenaga yang diserap dalam ujian hentakan. Keputusan eksperimen menunjukkan bahawa 'Auxetic Design 2' dan 'Polyurethane Foam' telah menunjukkan tenaga yang diserap tinggi dan telah digunakan sebagai bahan untuk dalaman topi keledar. Untuk ujian hentakan serong, empat topi keledar berbasikal diuji; Topi Keledar Kabuto, Topi Keledar Kenaf, Topi Keledar Flax dan Topi Keledar Flax Dengan Dalaman Auxetik. Kajian ini membuktikan bahawa flaks topi keledar dengan dalaman auxetic mempunyai pecutan linear yang paling rendah berbanding topi keledar yang lain diuji. Apabila digunakan sebagai bahan-bahan dalaman, struktur sel auxetic berpotensi boleh meningkatkan faktor keselamatan dalam bio-komposit aero topi keledar. Penemuan utama mendedahkan bahawa struktur sel auxetik terbukti untuk menjadi alternatif yang terbaik kepada bahan menyerap hentakan berbanding 'Crushable Foam', sebagai dalaman topi keledar.

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I certify that a Thesis Examination Committee has met on 30 November 2016 to conduct the final examination of Mohd Saffuan bin Yaakob on his thesis entitled "Auxetic Cell Structure as an Impact Absorbing Material in Bio-Composite Aero Helmet" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

Mohamed Thariq bin Hameed Sultan, PhD
Associate Professor Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Dayang Laila binti Abang Haji Abdul Majid, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Shahruddin Mahzan @ Mohd Zin, PhD
Associate Professor
Universiti Tun Hussein Onn
Malaysia
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 22 March 2017

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Faizal Mustapha, PhD
Associate Professor, Ir
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohamad Ridzwan Ishak, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

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Signature : _____
Name of Chairman of
Supervisory Committee : Faizal Bin Mustapha

Signature : _____
Name Of Member Of
Supervisory Committee : Mohd Ridzwan Bin Ishak

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LIST OF ABBRIVIATIONS

ANSI	American National Standards Institute
ASTM	American Society of Testing Material
CAD	Computer Aided Design
CATIA	Computer Aided Three-dimensional Interactive Application
CPSC	Consumer Product Safety Commission's standard
DARS	Data Acquisition & Reduction System
EN	European Standard
EPDM	Ethylene-Propylene-Diene-Monomer
FEA	Finite Element Analysis
KE	Kinetic Energy
KF	Kenaf Fiber
MAPP	Maleic Anhydride Polypropylene
MSN	Majlis Sukan Negara
PE	Potential Energy
PIV	Particle Image Velocimetry
PLA	Polylactide
RTM	Resin Transfer Molding
STL	STereoLithography
UPM	Universiti Putra Malaysia
TPNR	Thermoplastic Natural Rubber
TT	Time Trial
EPS	Expanded Polystyrene
PU	Polyurethane

CHAPTER 1

INTRODUCTION

This first chapter of thesis described the research background for the study, problem statement related to the research, objectives of the research, significant of the study and scope of the research work.

1.1 Research Background

One of the most important equipment must be used in the cycling industry is sport cycling helmet. Sport cycling helmets functions to protect the rider from the accelerated or decelerated by any impact. The helmet protects the head for the rider by reducing the impact especially on the brain. When the compression occurs for polystyrene liner, the helmet will reduce the force of an impact but no more protection and absorption direct to the skull and brain once the liner of the helmets is fully compacted. There is no answer to suggest that the helmets continue to decrease the energy absorption to protect the brain beyond their design limits. The cycling helmets those were manufactured and certified followed the safety standards.

One or more of the international standards will be the reference for the manufacturers of the sport cycling helmet. One with no body attaching known as standard test for helmet that only using a head form and tested in low speed impact testing. When the breaking process happens for the helmets, they surely do so ruinously. It's common for the helmets itself to fail early, before the polystyrene liner has been fully crushed. When some impact occurs to the helmets without the liner compressing, it is same as that no protection for user.

The material that currently used for the helmet interior may be made of crushable foam such as Expanded Polystyrene, Expanded Polypropylene, and Expanded Polyurethane. Nowadays crushable foam is the material that was regularly used because they are easy to mold and shape with heat and less cost to manufacture. But it does not absorb too much energy while having an impact. It has low toughness and strength towards the helmet.

A helmet protects against impact from overhead by absorbing energy through:

(a) Partial destruction or damage of interior and outer of the shell.
(b) Crushing of the protective padding if any.

Therefore, a new impact absorbing materials were desirable to be used for the helmet interior. Auxetic structure design is the best alternative which possesses excellent mechanical properties including energy absorbing and elastic. There were research focused on molecular auxetics, paying attention more to molecular designs with a view

towards nanotechnology (Yang, 2004). Since the cost in producing an impact absorbing material come from materials and production, the need for lower-cost and efficient technology becomes urgent.

In his publication in 1999, Alderson claimed to have introduced the novel elastic property with a negative Poisson's ratio that characterizes an auxetic material. Such a material becomes thicker width wise when stretched lengthwise, and thinner when compressed (Yunan Prawoto, 2012). This is apparently contradictory to the response of many common materials, which become thinner when stretched. When a load is applied to the structure in one direction (e.g., vertically), the structure expands in the perpendicular direction. Therefore, the structure gets fatter, resulting in a negative Poisson's ratio.

Various auxetic materials have been discovered and fabricated over the past decades, ranging from the macroscopic to microscopic and to the molecular levels. The following classification is mainly a classification via mechanical considerations.

Moreover, it is more appropriate to speak about auxetic behaviour in certain directions, since this effect also arises in given directions for composite materials and structures. Although a negative Poisson's ratio is allowed even in the case of the classical linear and isotropic elasticity, most researchers seem to forget this evidence and restrict their investigations to the range of positive Poisson's ratios. This lack of scientific information about the restricted number of applications makes the further development in this field difficult, although many of patents issued in the name of known companies certainly demonstrate the potential of having innovative applications and engineering products based on the auxetic behaviour effect.

Other than auxetic structure, natural fibers, which customarily were utilized, as fillers for thermosets, are presently turning into one of the quickest developing execution added substances for thermoplastics. These days' natural fiber reinforced polymers have turn out to be more predominant and utilized as a part of the automotive industry and construction industry since natural fibers display numerous favourable properties. These characteristics strands are recognized as minimal effort substantial, trivial and it is appropriate as natural distinct option for manufactured fiber (Basu, 2011).

Incorporating natural fibers material in cycling helmets may prompt a change in cyclist protective helmet industry. It is due to environmental issues concern by industry and because of the uncontrolled industrial development that could causes pollution to the environment. With concern from Malaysia government, the initiative to protect the environment from hazardous and negative effect were welcomed by the industries and researchers. Table 1.1 show comparison between natural fiber and synthetic fiber.

Table 1.1: Natural fiber and synthetic fiber comparison (Idicula, 2006).

Fiber	Advantages	Disadvantages
Natural fiber	Biodegradable Low density/price	Inhomogeneous quality Dimensional instability
Synthetic fiber	Moisture resistance Good mechanical properties	Difficult in recycle Relative high price

Despite the growing popularity of auxetic structure and natural fibers, limited research has been devoted to identify the applications for both materials. In this study, a new type of impact absorbed material was developed for helmet interior applications, particularly as interior of bio-composite aero helmet from previous research. Using experimental approach, this impact absorbed material was design base on auxetic design consideration and will need to possess drop weight impact test and oblique impact test. The new interior for bio-composite aero helmet should have efficient and cost-effective properties.

1.2 Problem Statements

The most important part in cycling is safety of the rider. Hayes state that a crash without helmet has 9.5 times more exposed the head to acceleration and force compare to a crash with helmet protection (Hayes, 1994). Without using a helmet, it may increase the potential of harm to head, skull and cerebrum part of brain.

The main mechanical properties that should be highlighted in sport cycling helmet interior materials are the energy absorption and impact resistance. It is also a main concern in other relevant industries such as aerospace, automotive and safety protection. Moreover, high energy absorption materials are desirable in designing the helmet interior. A new class of material such as auxetic structure cell has more potential to absorb energy if compare to existing material in helmet interior. It is important to include such material as a main mechanism which could absorb impact under limited crush event. In other point of view, the existing designs are limited to sustain under the impact loading on the helmet itself.

As the industry tried to decrease the reliance on petroleum-based powers and items, there is an expanding need to explore even more naturally inviting, reasonable materials to replace the current glass fiber and carbon fiber strengthened materials. Subsequently, consideration recently shifted to manufacture and properties of regular fiber fortified materials (Mohanty et al., 2002). Since research on flax composites are not widely undertaken in Malaysia, this study is aim at utilizing flax as a bio based

reinforcement for sport cycling helmet which could assist optimum performance of a cyclist.

1.3 Research Objectives

The main objective of this research is to design a new interior for bio-composite aero helmet comply to standards set by The Consumer Product Safety Commission of bike helmet standard.

Along with the main objective, there are several specific objectives including:

1. To design an impact absorbing material from auxetic cell structure design consideration.
2. To investigate the impact behaviour and the reliability of the design to absorb impact energy.
3. To incorporate the impact absorbing material design as the core material for the interior of the sport cycling helmet.
4. To evaluate the performance of helmet with the new interior design in oblique impact test and compared the linear acceleration to other established helmets.

1.4 Significance Of The Study

Previous study of sport cycling helmets has explored any possibilities to increase the speed and proficiency of the helmet by using the innovative knowledge and using any feasible technique in their research. In this present study, the studies are focusing on finding alternate method to improve the energy absorption efficiency of the sport cycling helmets. Now, the application of manufacturing product involves material that only could be manufactured easily but still effect the cyclist due to impact. By incorporate the auxetic structure cell, the helmet could improve the energy absorption efficiency.

Besides, the other studies were conducted shows that auxetic structure is still limited, thus it need to be developed further (Zi-Xing Lu et al, 2011). In this study, the design of new impact absorbing material was proposed as the interior for sport cycling helmets. The analytical result from previous researches were used as a baseline to produce mechanical properties needed in the impact absorbing material. New method to fabricate the auxetic structure was establish in this research. The method could provide an alternative fabrication technique to fabricate auxetic structure. To compare with the previous published methods, this method could produce auxetic structure with uniform size and shape. This method could be a significant outcome for this research because it reduces the production cost and considered as economical way to produces auxetic structure.

1.5 Scope Of Works

In achieving the objectives of this study, experimental works consist of drop weight impact test following Standard Test Method for ASTM D7136 / D7136M – 15 and oblique impact test to comply with EN 1078 specifies requirements and test methods for bicycle helmets, skateboard and roller skate helmets were conducted. For drop weight impact test, the specimens were fabricated using flax fiber and resin as the shell. Meanwhile, the impact absorbing material printed using 3D printer. The impact absorbing material, Auxetic Design 1 and Auxetic Design 2 were compared with Polyurethane Foam and Expanded Polystyrene Foam. The data from the tests were analysed and evaluated. Specimen that absorb the highest impact energy will be the core material for the helmet interior. Helmet fabricated using moulding technique and hand lay-up process. The new absorbing materials installed as interior of the helmet and undergoes oblique impact test. Four type of helmet been compared, Kabuto Helmet, Flax Helmet, Kenaf Helmet and Flax with Auxetic Interior Helmet. Data been analyse and compared with requirements stated.

1.6 Thesis Organization

The overall thesis covers the development of the auxetic design structure for interior of sport cycling helmets. This is due to the energy absorbed during the impact event. The thesis is organized in the following way.

Chapter 2: Literature Review
This chapter discuss the literature review on related published papers regarding to sport cycling helmets, bio-composite materials, interior helmet design, drop weight impact test and oblique impact test

Chapter 3: Methodology
Chapter 3 will highlight the methodology implementing in the research such as design of the auxetic structure, fabrication of helmet shell and interior, drop weight impact test and oblique impact test are being discussed. More detailed information on the materials used, the apparatus and the technique is given in this section.

Chapter 4: Results and Discussion
This chapter provides the results for mechanical testing of drop weight impact test and oblique impact test subjected to the lab scale specimens. A comparison between results is also depicted in this chapter to ensure consistency and good result repeatability. This chapter also discuss the comparison of each test.

Chapter 5: Conclusions and Recommendations
The final overview of the thesis findings provides a comprehensive conclusion in which all the steps taken in preparing this thesis are aligned with the problem statement and objectives.

REFERENCES

Alam, F., Chowdhury, H., Elmir, Z., Sayogo, A., Love, J., & Subic, A. (2010). An experimental study of thermal comfort and aerodynamic efficiency of recreational and racing bicycle helmets. Procedia Engineering, 2(2), 2413–2418.

Alderson, A., Alderson, K.L., 2007. Auxetic Materials. Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering 221, 565-575.

Alderson A, et al. Auxetic polymeric filters display enhanced defouling and pressure compensation properties. Membr Technol. 2001; 137:6–8.

Allen T, Shepherd J, Hewage T, Senior T, Foster L, & Alderson A. Low-kinetic energy impact response of auxetic and conventional open-cell polyurethane foams, Phys. Status Solidi B. doi: 10.1002/pssb.201451715 (2015).

Basu, B. (2011). Biocomposite textile. Textile review (pp. 19-32).

Begum K. and Islam M.A. (2013) Natural Fiber as a substitute to Synthetic Fiber in Polymer Composites Vol. 2(3), 46-53, April 2013 SSN 2278 – 9472.

Bos, H.L (2004). The Potential of Flax Fiber as Reinforcement for Composite Materials. Ph.D. Thesis, Eindhoven University, Eindhoven, The Netherlands. Retrieved 2015.

Cassidy, J.D., Cancelliere C, Carroll LJ. (2014). Systematic review of selfreported prognosis in adults after mild traumatic brain injury: results of the International Collaboration on Mild Traumatic Brain Injury Prognosis, Arch Phys Med Rehabil 95 (3 Suppl. 2): 132-151.

CEN European Standard Helmets for Pedal Cyclists and for Users of Skateboards and Roller Skates, EN1078, February, (1997). The standard states that the following countries are bound by EC rules to implement it in 1997: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Ching, O.T. (2010, April 2). Malaysian Will Continue to Value Add Kenaf Industry. New Straits Times.

Consumer Product Safety Commision. (1998). CPSC 16 CFR Part 1203 - Safety Standard for Bicycle Helmets. Federal Registry, 63(46), 11711–11747.

Saied M. Darwish, M. Usman Aslam. Development and analysis of different density Auxetic Structure cellular structure. January 2015

Dorata Jasinska, Malgorzata Janus-Michalska, Jerzy SMardzewski. A study on the Design of Auxetic Structure of seat skeleton. 2012.

Doval, P. N. (2012). Aerodynamic Analysis and Drag Coefficient Evaluation of Time-Trial Bicycle Riders. Theses and Dissertations. Paper 28. http://dc.uwm.edu/etd/28

E. A. Friis, R. S. Lakes, and J. B. Park, "Negative Poisson's ratio polymeric and metallic foams", Journal of Materials Science, vol. 23, pp. 4406-4414, 1988.

Evans, K. E. and Alderson, A. (2000), Auxetic Materials: Functional Materials and Structures from Lateral Thinking. Adv. Mater., 12: 617–628.

Friis E, Lakes R, Park J. Negative Poisson's ratio polymeric and metallic foams. Journal of Materials Science 1988; 23:4406-4414.

Ganesh, (2008). Biocomposites Draft Report: Synthesis and characterization of biocomposite material, National Institute of Technology Rourkula, Kispotta, U. (n.d.).

Gaspar N, (2005) Quantitative analysis of the microscale of auxetic foams.

Grima JN, et al. Do zeolites have negative Poisson‟s ratios? Adv Mater. 2000;12(24):1912–8.

Hayes, R.L., Dixon, C.E. Neurochemical changes in mild head injury. Semin Neurol. 1994; 14:25-31.

IMATEK. Impact Test Systems Model IM1-C Impact Test System. Operator & Maintenance Manual. 2013.

Idicula, M.; Boudenne, A.; Umadevi, L.; Ibos, L.; Candau, Y.; Thomas, S (2006). Thermophysical properties of natural fiber reinforced polyester composites. Compo. Sci. Technol, 66, 2719–2725. Retrieved 2015.

Ishak, M. R., Leman, Z., Sapuan, S. M., Edeerozey, a M. M., & Othman, I. S. (2010). Mechanical properties of kenaf bast and core fibre reinforced unsaturated polyester composites. IOP Conference Series: Materials Science and Engineering.

J.N. Grima, A. Alderson, K.E. Evans. Auxetic behavior from rotating rigid units. 2005.

J.N. Grima, A. Alderson, K.E. Evans. Phys. Status Solidi B 242 (2005) 561–575.

J.N. Grima, E. Manicaro, D. Attard, Phys. Soc. 467 (2010) 439–458.

J.N. Grima, K.E. Evans, J. Mater. Sci. 41 (2006) 3193–3196.

J. Schwerdtfeger, P. Heinl, R. F. Singer, and C. Korner. Auxetic cellular structures through selective electron-beam melting. 2009.

Joshi S.V., L.T. Drzal, A.K. Mohanty,S. Arora, (2003) Are natural fiber composites environmentally superior to glass fiber reinforced composites. Retrieved 2015.

Joshua M. Duell (2004). Advanced Topics in Characterization of Composites: Impact Testing of Advanced Composites. pg 102-106.

J. Schwerdtfeger, P. Heinl, R. F. Singer, and C. Korner, "Auxetic cellular structures through selective electron-beam melting", Phys. Status Solidi B, vol. 247, no. 2, pp. 269–272, 2010 / DOI 10.1002/pssb.200945513.

Kleiven, S. (2013). Why Most Traumatic Brain Injuries are Not Caused by Linear Acceleration but Skull Fractures are. Frontiers in Bioengineering and Biotec

Lande P.R. ., Toradmal K.P.. Pathan F.A. Study of Compliant Mechanisam. IJIRSET, Volume 3, Special Issue 4, April 2014. hnology, 1, 15.

Larsen, U.D., Sigmund, O., Bouwstra, S., 1997. Design and Fabrication of Compliant Micromechanisms and Structures with Negative Poisson's Ratio. Journal of Microelectromechanical Systems 6, 99-106.

L. Gibson and M. Ashby, Cellular Solids, second ed. (Cambridge University Press, Cambridge, UK, 1997).

Metz, R. (2007). Impact and Drop Testing with ICP force sensors. Sound and Vibration, (February), 18–20.

Mills, N. J., & Gilchrist, A. (1991). The Effectiveness of Foams in Bicycle and Motorcycle Helmets, Accidents Anaysis & Preview. 23, 153-163.

Mills N. J., in: Materials in Sports Equipment, edited by M. J. Jenkins, Woodhead, Cambridge, 2003, chap. 2.

Mills, N. J. (1990). Protective capability of bicycle helmets. British Journal of Sports Medicine, 24(1), 55–60.

Mohanty A.K, M. L. (2002). Sustainable Bio-Composite from Renewable Resources: Opportunities and Challenges in the Green Materials World. Journal of Polymers and the Environment, 8.

Mohanty AK, Drazl LT, Misra M. Engineered natural fiber reinforced polypropylene composites: influence of surface modification and novel powder impregnation processing. J Adhes Sci Technol 2002;16(8):999-1015.

Mohd Na'im Abdullah (2015). Oblique Impact And Aerodynamic Analysis Of A Biocomposite Sport Cycling Helmet.

Mozafar Shokri Rad, Yunan Prawoto, Zaini Ahmad. Analytical solution and finite element approach to the 3Dre-entrant structures of auxetic materials. Mechanics of Materials 74 (2014) 76-87.

Murtaza N. Ali, Ihtesham Ur Rehman. An Auxetic structure configured as oesophageal stent with potential to be used for palliative treatment of oesophageal cancer; development and in vitro mechanical analysis. 6 December 2011.

Nave, R. (2001). Hyper Physics, Mechanics, National Science Teacher Association.

Naveen Ravirala, Mohammad Sanami, Kim Alderson, Andrew Alderson. Auxetic material for sports applications. 2014.

N. Gaspar, X. Ren, C. Smith, J. Grima, K. Evans, Acta Mater. 53 (2005) 2439– 2445.

Nicholas Iwaskow. Schutt Sports Scores with Football Helmet Digitization. 10 Mar, 2011. Retrieved from http://www.cadalyst.com/early-design/reverse-engineering/ schutt-sports-scores-with-football-helmet-digitization-13736

Otte, D. (1989). Injury Mechanism and Crash Kinematic of Cyclists in Accidents - An Analysis of Real Accidents. SAE Technical Paper 892425.

P. Heinl, A. Rottmair, C. Ko¨rner, and R. Singer, Adv. Eng. Mater. 9, 361 (2007).

P. Pastorino, F. Scarpa, S. Patsias, J. Yates, S. Haake, and M. Ruzzene, Phys. Status Solidi B 244, 955 (2007).

Ramanaiah, K., Ratna Prasad, a. V., & Hema Chandra Reddy, K. (2012). Thermal and mechanical properties of waste grass broom fiberreinforced polyester composites. Materials and Design, 40, 103–108.

Ray, D. & Rout, J. (2005). Natural Fibers, Biopolymers and Biocomposites (pp 291-341). USA: CRC Press.

R. Kureta and Y. Kanno. "A mixed integer programming approach to designing periodic frame structures with negative Poisson's ratio," Optimization and Engineering, vol. 15, no. 3, pp. 773–800, 2014.

R. Lakes, R. Witt, Inter. J. Mech. Eng. Educ. 30 (2002) 50–58.

Rowell, D. P., C. K. Folland, K. Maskell, and M. N. Ward. (1996). Further analysis of simulated interdecadal and interannual variability of summer rainfall over tropical north Africa—Reply, Q. J. R. Meteorol. Soc., 122, 1007– 1013.

Schwerdtfeger, J., Wein, F., Leugering, G., Singer, R. F., Körner, C., Stingl, M. and Schury, F. (2011), Design of Auxetic Structures via Mathematical Optimization. Adv. Mater., 23: 2650–2654.

S. McDonald, N. Ravirala, P. Withers, and A. Alderson, Scr. Mater. 60, 232 (2009).

Snell B 90, 1998. Standard For Protective Headgear For Use In Bicycling. Snell Memorial Foundation, Inc. 1990.

Snell B95, 1995. STANDARD FOR PROTECTIVE HEADGEAR 1998 revision, For Use with Bicycles. Snell Memorial Foundation, Inc.

Stavroulakis GE. Auxetic behaviour: appearance and engineering applications. Phys Status Solidi. 2005;242(3):710–20.

Tom Allen, Nicolo Martinello, Davide Zampieri, Trishan Hewage, Terry Senior. Aucetic Foam for sport safety applications. S.l. : Elsevier Ltd, 2015.

Verpoest, I. (2012). A General Introduction to Composites, Highlighting the Advantages of Flax and Hemp Composites, Flax and Hemp Fibers: A Natural Solution for The Composite Industry, Biofiber Reinforcements in Composite Materials. Woodhead Publishers.

Webber, C. L., Whitworth, J., & Dole, J. (1999). Kenaf (Hibiscus cannabinus L.) core as a containerized growth medium component. Industrial Crops and Products, 10(2), 97–105.

Williams, G.I. and Wool, R.P. (2000). Composites from Natural Fibers and Soy Oil Resins. Applied Composite Materials 7:421-432.

W. Yang, Z. Li, W. Shi, B. Xie, M. Yang, J. Mater. Sci. 39. 3269–3279 (2004).

Yunan Prawoto. Seeing auxetic materials from the mechanics point of view: A structural review on the negative Poisson's ratio. Computational Materials Science 58 (2012) 140–153 (2012).

Y. Liu, H. Hu, Sci. Res. Essays 5 (2010) 1052–1063.

Y. Wang and R. Lakes, Solids Struct. 39, 4825 (2002).