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DEVELOPMENT AND CHARACTERIZATION OF KEVLAR/*COCOS NUCIFERA* L. SHEATH/EPOXY HYBRID COMPOSITES AND GRAPHENE NANOPLATELET- MODIFIED HYBRID NANOCOMPOSITES FOR BALLISTIC APPLICATIONS

NAVEEN JESU AROCKIAM

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By

NAVEEN JESU AROCKIAM

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DEVELOPMENT AND CHARACTERIZATION OF KEVLAR/*COCOS NUCIFERA* L. SHEATH/EPOXY HYBRID COMPOSITES AND GRAPHENE NANOPLATELET- MODIFIED HYBRID NANOCOMPOSITES FOR BALLISTIC APPLICATIONS

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NAVEEN JESU AROCKIAM

August 2019

Chairman : Edi Syams b. Zainudin, PhD
Faculty : Engineering

Kevlar 29 is the most widely used body armor material, since it possesses higher impact resistance compared to other man-made synthetic fibers, such as carbon, glass, etc. Even though Kevlar fabric provides an acceptable range of protection, it is not biodegradable and its manufacturing process is very harmful to the environment. This research has focused on evaluating the effect of hybridizing natural fiber with Kevlar 29 and the influence of adding GNP (Graphene nanoplatelets) on the mechanical, moisture diffusion, morphological, structural, ballistic performance, thermal degradation and viscoelastic properties of laminated composites. Through AHP (Analytical hierarchy process) method, naturally woven novel *Cocos nucifera sheath* (CS) was identified as a potential natural fiber to be hybridized with Kevlar for body armour applications. Laminated composites were fabricated by incorporating Kevlar and *Cocos nucifera* sheath layers in the epoxy matrix through hand lay-up method followed by hot pressing. GNP were added with epoxy through ultrasonication process. The mechanical, ballistic, thermogravimetric and dynamic mechanical testing's were performed as per international standards. The mechanical and moisture diffusion properties analysis revealed that the hybrid Kevlar/CS (75/25) composites exhibited better mechanical and moisture resistance behavior among the hybrid composites. Moreover, addition of GNP improved the tensile, flexural, impact and interlaminar shear properties of laminated composites. However, optimal wt. % of GNP varies with different laminates. Moisture diffusion analysis showed that the laminates with 0.25wt % of GNP content efficiently hinder water uptake by closing all the unoccupied pores inside the laminate. Morphological investigations (SEM and FESEM) have proven that addition of GNP improved the interfacial adhesion and dispersion. Structural (XRD and

FTIR) analysis reveals that at 0.25wt% of GNP, all the hybrid composites have shown better crystallinity index and the functional groups presents in the GNP can form a strong interactions with the fibers and matrix. The obtained ballistic results revealed that hybrid composites and CS/epoxy composite panels exhibited similar energy absorption and ballistic limit compared to Kevlar/epoxy composites due to CS's chemical composition, architecture, and unique shock wave dissipation mechanism. Moreover, addition of GNP improved the energy absorption by 8.5% (nine plies) and 12.88% (12 plies) and the ballistic limit by 4.28% (nine plies) and 6.17% (12 plies), respectively of Kevlar/epoxy/GNP composites at 0.25 wt. %. However, hybrid Kevlar/CS/epoxy/GNP composites and CS/epoxy/GNP laminated composites didn't show significant improvement after adding GNP. The obtained TGA results showed that Kevlar/CS (75/25) hybrid composites exhibited comparable thermal stability with Kevlar/epoxy composites. Differential scanning calorimetry (DSC) results revealed that hybrid composite offers a virtuous resistance or stability towards heat in the epoxy composites. Viscoelastic analysis results showed that the storage modulus (E') and loss modulus (E") of Kevlar/CS (75/25) hybrid composites were higher among the laminates due to improved interfacial interactions and effective stress transfer rate. Also, inclusion of GNP enhanced the thermal stability and viscoelastic properties of hybrid composites due to effective crosslinking which improves the stress transfer rate. Hence, this new eco-friendly material (*Cocos nucifera* sheath) will efficiently replace Kevlar fabric in the protective applications.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN DAN KARAKTERISASI KEVLAR / *COCOS NUCIFERA* L. SHEATH / EPOXY HYBRID KOMPOSIT DAN GRAPHENE NANOPLATELET-MODIFIED NANOCOMPOSIT HYBRID UNTUK APLIKASI BALLISTIC

Oleh

NAVEEN JESU AROCKIAM

Ogos 2019

Pengerusi : Edi Syams b. Zainudin, PhD
Fakulti : Kejuruteraan

Kevlar 29 paling banyak digunakan sebagai bahan perisai badan kerana ianya mempunyai rintangan hentaman yang lebih tinggi berbanding serat sintetik buatan manusia yang lain, seperti karbon, kaca, dan sebagainya. Walaupun kain Kevlar menyediakan perlindungan yang tinggi, namun ianya tidak boleh biodegradasi dan proses pembuatannya sangat berbahaya kepada alam sekitar. Kajian ini menumpukan kepada penilaian kesan serat semulajadi hibridisasi dengan Kevlar 29 dan pengaruh penambahan GNP (Graphene nanoplatelets) kepada sifat-sifat mekanik, penyebaran kelembapan, morfologi, struktur, prestasi balistik, kemerosotan terma dan sifat viskoelastik komposit berlapis. Melalui kaedah AHP (proses hirarki analisis), novel semulajadi Cocos nucifera sarung (CS) telah dikenalpasti sebagai serat asli yang berpotensi untuk dikombrinasi dengan Kevlar untuk aplikasi perisai badan. Komposit berlapis telah difabrikasi dengan menggabungkan lapisan sarung Kevlar dan Cocos nucifera dalam matrik epoksi melalui kaedah layangan tangan diikuti dengan penekan panas. GNP ditambah dengan epoksi melalui proses ultrasonication. Ujian mekanikal, balistik, termogravimetrik dan dinamik telah dijalankan berdasarkan piawaian antarabangsa. Analisis sifat penyebaran mekanikal dan kelembapan mendedahkan bahawa komposit Kevlar / CS (75/25) hibrid menunjukkan kelakuan rintangan mekanikal dan kelembapan yang lebih baik dibandingkan dengan komposit hibrid yang lain. Selain itu, penambahan GNP telah meningkatkan sifat ricih, lentur, kesan dan sifat geseran interlaminar komposit berlapis. Walau bagaimanapun, berat optimum wt % daripada GNP berbeza dengan laminates yang berlainan. Analisis penyembaran lembapan menunjukkan bahawa laminates dengan 0.25wt% kandungan GNP cekap menghalang penyerapan air dengan menutup semua liang kosong di dalam lamina. Penyiasatan morfologi (SEM dan FESEM) telah membuktikan bahawa penambahan GNP meningkatkan penyebaran dan lekatan antara muka. Analisis struktur (XRD dan FTIR) mendedahkan bahawa pada 0.25wt% GNP, semua komposit hibrid telah menunjukkan indeks crystallinity

yang lebih baik dan kumpulan-kumpulan fungsi yang dibentangkan dalam GNP boleh membentuk interaksi yang kuat dengan serat dan matriks. Keputusan balistik yang diperolehi menunjukkan bahawa komposit hibrid dan panel komposit CS / epoksi mempamerkan penyerapan tenaga yang sama dan had balistik berbanding dengan komposit Kevlar / epoksi kerana komposisi kimia, seni bina, dan mekanisme penyebaran gelombang kejutan yang unik. Tambahan pula, penambahan GNP telah meningkatkan penyerapan tenaga sebanyak 8.5% (sembilan lapisan) dan 12.88% (12 lapisan) dan had balistik sebanyak 4.28% (sembilan lapisan) dan 6.17% (12 lapisan), masing-masing komposit Kevlar / epoxy / GNP pada 0.25 wt. %. Walau bagaimanapun, komposit Kevlar / CS / epoxy / GNP hibrid dan komposit CS / epoxy / GNP berlapis tidak menunjukkan peningkatan yang ketara selepas penambahan GNP. Hasil TGA yang diperoleh menunjukkan bahawa komposit hibrid Kevlar / CS (75/25) mempamerkan kestabilan haba setanding dengan komposit Kevlar / epoksi. Hasil pengoksidaan kalori (DSC) yang berbeza menunjukkan bahawa komposit hibrid menawarkan rintangan yang baik atau kestabilan terhadap haba dalam komposit epoksi. Hasil analisis Viscoelastic menunjukkan bahawa modulus penyimpanan (E') dan modulus kehilangan (E") daripada komposit hibrid Kevlar / CS (75/25) lebih tinggi di antara laminates disebabkan oleh interaksi antara muka yang lebih baik dan kadar pemindahan tekanan yang berkesan. Selain itu, kemasukan GNP meningkatkan kestabilan terma dan sifat viskoelastik komposit hibrid disebabkan oleh persilangan yang berkesan yang dapat meningkatkan kadar pemindahan tegasan. Oleh itu, bahan mesra alam yang baru (sarung Cocos nucifera) akan menggantikan kain Kevlar dengan berkesan dalam aplikasi perlindungan.

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

Edi Syams bin Zainudin, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohamed Thariq Bin Hameed Sultan, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohammad Jawaid, PhD
Senior Fellow Researcher
Institute of Tropical Forestry and Forest Product,
Universiti Putra Malaysia
(Member)

Ridwan Bin Yahaya, PhD
Research officer
Protection and Biophysical Technology
Science and technology Research Institute for Defence
(Member)

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

Date:

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Signature:	
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Signature:	
Name of Member of Supervisory Committee:	Assoc. Prof. Ir. Ts. Dr. Mohamed Thariq bin Haji Hameed Sultan
Signature:	
Name of Member of Supervisory Committee:	Dr.Mohammad Jawaid
Signature:	
Name of Member of Supervisory Committee:	Dr.Ridwan Bin Yahaya

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LIST OF ABBREVIATIONS

FRP	Fiber reinforced polymer
GNP	Graphene nanoplatelets
AHP	Analytical hierarchy process
CS	Cocos nucifera sheath
UHMWPE	Ultra high-molecular-weight polyethylene
GO	Graphene oxide
NFC	Natural fiber composites
ILSS	Interlaminar shear strength
TGA	Thermogravimetric analysis
DMA	Dynamic mechanical analysis
PCM	Pairwise comparison matrix
WPIM	Weighted property index method
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
CR	Consistency Ratio
CI	Consistency Index
TS	Tensile strength
TM	Tensile modulus

LIST OF SYMBOLS

τ	Interlaminar shear strength (N/mm^2)
W_b	Breaking load (N)
b	Width of the composite sample (mm)
h	Thickness of the composite sample (mm)
D	Diffusion coefficient (mm^2/s)
θ	Slope of the moisture absorption curve
Q_s	% of moisture absorption at saturation
t	Initial thickness of the sample (mm)
I_c	Intensities of crystalline peak
I_a	Intensities of amorphous peak
v_i	Impact velocity (m/s)
v_r	Residual velocity (m/s)
$E_{(abs)}$	Energy absorption (J)
V_{50}	Ballistic limit (m/s)
$E_{(specific)}$	Specific energy absorption ($J/Kg/m^2$)
wt %	Weight percentage.
λ_{max}	Principal Eigen vector

CHAPTER 1

INTRODUCTION

1.1 Background

The ever-burgeoning need for humanity to produce lighter, tougher and cost effective material has led to the development of composites. In particular, fiber reinforced polymer (FRP) composites have been introduced in 1960's due to the limitations of conventional metallic materials (Bajaj, 1997) . Ever since its creation, composites have found themselves to be ubiquitous. FRP composites have been predominantly used in aerospace, automobile, defence, construction and in marine sectors due to its superior mechanical, ballistic, thermal, viscoelastic and non-corrosive behaviour (Sanjay et al., 2018; Shah, Schubel, & Clifford, 2013; J. Zhang, Ju, Jiang, & Peng, 2013).

High performance aramid fibers (Kevlar 29) are widely used as a reinforcement in the polymer matrix for ballistic applications such as bullet proof helmets, body armour vest, and other armor systems. Personal body armor could be classified into soft armor and hard armor. Soft body armor contains multiple layers of fabrics up to 50 layers (A. Hani, Roslan, Mariatti, & Maziah, 2012) . On the other hand, hard body armors are generally made up of multi layered structures. Ballistic impact produces shock waves which may cause severe trauma injuries to the soldiers. Kevlar fabric based protection system, what defense industries are using now provides acceptable range of protection to the soldiers. However, disposal of Kevlar releases enormous amount of carbon dioxide into the atmosphere. Moreover, it affects the eco system and pollutes the environment.

On the other hand, aramid fabrics are costlier. Hence, it is imperative to find an alternative material to Kevlar fabric (P. Liu & Strano, 2016; Wambua, Ivens, & Verpoest, 2003). Due to the awareness towards eco-friendly materials, researchers have devoted their work to develop sustainable materials which are biodegradable and creates no environmental issues. The utilization of natural fibers have been encouraged by "end of life" regulation in Europe and Asia (Holbery & Houston, 2006). The main advantages of using natural fibers are low density, non-abrasive, non-corrosive, inherent biodegradability, low cost, higher specific strength and stiffness, easily available and recyclable (M Jawaid, Khalil, & Bakar, 2011). Despite its merits, major impediments of using natural fibers are hydrophilic nature, limited thermal stability and poor adhesion with adjacent counterparts (Espert, Vilaplana, & Karlsson, 2004; L. Pothan, Cherian, Anandakutty, & Thomas, 2007).

Hybrid composites contains more than two discontinuous or continues phases. The main advantage of hybrid composites relies on the fact that the benefit of one type of fiber could surpass the limitations of the other fiber (Costa, Fonseca, Serra, & Coelho, 2016; Md Shah, Sultan, & Jawaid, 2019). Hybridizing natural and synthetic fibers will provide superior properties for advanced application. Moreover, it reduces the usage of synthetic fiber in polymeric composites (Joshi, Drzal, Mohanty, & Arora, 2004).

Due to the advancement in nanotechnology, modifying a polymer matrix with nano fillers has become an interesting approach to improve the properties of FRP composites (Umboh, Adachi, Oishi, Higuchi, & Major, 2013). Many researchers have evaluated the effect of adding different nano fillers (graphene, carbon nano tube, nano clay, etc.) ranging from 0.01 to 5 wt. % on the mechanical properties of nano composites. The addition of nano fillers significantly improved the mechanical properties of polymeric composites(Schilde, Schlömann, Overbeck, Linke, & Kwade, 2015; Zaman et al., 2011). In particular, graphene nanoplatelets (GNP) has been considered as an efficient nano filler in the polymeric composites due to its higher mechanical strength, thermal and chemical stability (Ahmadi-Moghadam, Sharafimasooleh, Shadlou, & Taheri, 2015; G. Zhang, Wang, Dai, & Huang, 2016). Moreover, it is abundantly available and cost effective. Due to the higher specific surface area, GNP could enhance the stress transfer rate. At an optimal loading condition, GNP filled polymeric composites have shown superior mechanical and thermal properties (Hossain, Chowdhury, & Bolden, 2016). Hybridizing natural and synthetic materials together with nanofiller modified epoxy composites has become an interesting and innovative research approach to achieve higher mechanical, ballistic and thermal properties for advanced structural applications.

In this research, the potential of using natural fiber as an alternative to man-made aramid fiber (Kevlar) through hybridization was explored for body armour applications. This research work focussed on selecting the most suitable natural fiber to be hybridized with Kevlar fabric using analytical hierarchy process (AHP) and fabrication of hybrid Kevlar/natural fiber reinforced GNP modified epoxy composites with different laminate configuration by hand lay-up method followed by hot pressing. Then, evaluating the effect of hybridizing natural fiber with Kevlar and the influence of adding GNP on the mechanical, moisture absorption, morphological, structural, ballistic, thermal and dynamic mechanical properties of laminated composites.

1.2 Problem Statements

Synthetic fiber reinforced polymeric composites offer many advantages such as higher specific strength, stiffness, corrosion resistance and enhanced fatigue properties compared to conventional metallic materials. Kevlar fiber based polymeric composites are widely used in ballistic applications due to its ability to resist high kinetic energy projectiles. Even though these aramid fibre composites having higher specific strength, impact strength and corrosion resistance most of the fibres are manufactured from petroleum based resources (P. Liu & Strano, 2016) . Depletion of petroleum based resources urges the researchers to find a sustainable replacement. Moreover, disposal of Kevlar releases enormous amount of carbon dioxide which pollutes the environment (Wambua et al., 2003). Hence, it is imperative to find an alternate material to man-made Kevlar fabric for armour applications. In addition, usage of Kevlar fabric increases the overall fabrication and product cost (Joshi et al., 2004).

Currently, natural fiber reinforced polymer composites are efficiently employed in automotive (Holbery & Houston, 2006), packaging (Chaudhary, Borkar, & Mantha, 2010), insulation (X.-y. Zhou, Zheng, Li, & Lu, 2010), sound absorbing panels (Fouladi, Nor, Ayub, & Leman, 2010) and in construction sectors (Ali, Liu, Sou, & Chouw, 2012) . The possibility of utilizing natural fibers for ballistic applications were explored (Benzait & Trabzon, 2018a). It has been found that plant fibers or natural fibers can act as an alternative and sustainable replacement to synthetic fibers. The merits of using plant fibers encouraged many researchers to utilize natural fiber for ballistic applications (Wambua, Vangrimde, Lomov, & Verpoest, 2007). Fibers extracted from natural resources are eco friendly and biodegradable. Also, natural fibers are abundantly available, inexpensive,light weight,non abrasive and holds higher specific strength and stiffness (Joshi et al., 2004). Derspite its advantages,the limitatios of using natural fibers are are moisture absorption, limited thermal stability and poor adhesion with adjacent counterparts (Espert et al., 2004; L. Pothan et al., 2007).

FRP composites for high velocity impact or ballistic applications require high specific strength and stiffness,impact resistance,crack resistance and low density. Interestingly, the requirements of ballistic composites differ from other structural laminated composites. Higher fiber/matrix adhesion may decline the ballistic behaviour (Schuster, 1970). However, in case of structural laminated composites improved interfacial properties are essential to achieve higher mechanical properties. The properties of ballistic composites includes moderate fiber/matrix adhesion, higher fiber loading, moderate fiber impregnation and voids (Cheeseman & Bogetti, 2003; Yahaya, Sapuan, Jawaid, Leman, & Zainudin, 2016c).

Hence, hybridization of *Cocos nucifera* sheath (CS) and Kevlar in nano filler (GNP) modified epoxy matrix will provide superior properties. Also, the benefits of multi scale filler reinforced hybrid polymeric composites relies on the fact that the advantage of one type of constituent could surpass the limitations of another constituent of hybrid composites (Costa et al., 2016). Also, hybrid *Cocos nucifera* sheath/Kevlar composites will reduce the utilization of Kevlar fabric in the polymeric composites for ballistic applications. Hence, this research has been dedicated to reduce the man-made petroleum resource based Kevlar fabric with *Cocos nucifera* sheath in the GNP modified epoxy composites by evaluating the mechanical, moisture absorption, morphological, structural, ballistic, thermal and dynamic mechanical properties

1.3 Objectives

1. Analysing the design criteria for body armour and selection of a suitable natural fiber to be hybridized with Kevlar fabric.
2. Examining the effect of hybridizing *Cocos nucifera* sheath and the influence of adding GNP on the Mechanical (tensile, flexural, impact, interlaminar shear stress) moisture diffusion, morphological and structural behaviour of Kevlar / *Cocos nucifera* sheath hybrid composites.
3. Investigating the effect of hybridizing Cocos nucifera sheath and the effect of adding GNP on the ballistic performance of Kevlar/ *Cocos nucifera* sheath hybrid composites.
4. Analysing the effect of hybridizing Cocos nucifera sheath and GNP on the thermal and dynamic mechanical properties of Kevlar / *Cocos nucifera* sheath hybrid composites.

1.4 Significance of this study

Now a days, due to eco legislation and environmental pollution many researchers have focused on reducing the utilization of petroleum based materials and products. This goal have motivated the researchers to identify a promising natural materials which are eco friendly and cost effective. Natural fibers have become an efficient alternative to synthetic fibers in automobile,aircraft,defense and in marine sectors due to its high strength to weight ratio, inherent biodegradability and low cost.

Only few studies have reported the utilization of natural fibers in the defense sectors . In particular, for body armour application.The most important properties to be considered while designing a body armour materials are mechanical,ballistic and thermal properties. It is well known that the synthetic fiber holds superior properties compared to natural fibers. However, hybridizing natural and synthetic fibers will combine the advantage of both natural and synthetic materials and results in superior properties.

On the other hand, nano filler modified epoxy composites in the FRP composites has become an intresting research approach to improve the mechanical, ballistic and thermal properties of the composites. Hence, hybridizing Kevlar and *Cocos nucifera* sheath in the GNP modified epoxy composites will improve the performance of the composites and reduce the utilization of Kevlar. It is expected that ,this research will open new avenues in the ballistic materials research for armour applications.

1.5 Scope of this study

The scope of the current research work has been limited to experimental evaluation of mechanical ,ballistic and thermal properties of natural/Kevlar fabric reinforced GNP modified epoxy composites for body armour applications. Prior to experimentations the natural fiber to be hybridized with Kevlar was selected by using analaytical hierarchy process. The materials utilized for this study were limited to Kevlar 29, *Cocos nucifera* sheath, graphene nanoplatelets and epoxy resin. The laminated composites were fabricated through handlay-up method followed by hot pressing. The influence of adding different wt % of *Cocos nucifera* sheath and GNP on the mechanical properties (tensile, flexural, impact and interlaminar shear stress), morphological, water uptake behaviour, ballistic performance, thermal degradation and viscoelastic properties of laminated composites were evaluated .

1.6 Thesis outline

This thesis has been structured into 12 chapters according to alternative thesis format of Universiti Putra Malaysia (UPM) based on the publications on which each chapter (4-11) contains its introduction, materials, methods, results, discussions and conclusions. Brief description of each chapter has been addressed in the following section.

Chapter 1

This chapter provides information about the background of this study, problem statements, objectives, scope and significance of the study with thesis outline.

Chapter 2

This chapter presents a detailed and comprehensive literature review of natural fiber composites, hybrid synthetic/natural fiber composites, nano filler modified polymer composites and its mechanical properties, ballistic performance in terms of energy absorptions & ballistic limit, thermal degradation and dynamic mechanical properties.

Chapter 3

Chapter 3 addresses the detailed description of materials, methodology and characterization of this study.

Chapter 4 (Objective 1: Article 1)

This chapter deals with the first objective supported by the first research article entitled “Selection of natural fiber for hybrid Kevlar/natural fiber reinforced polymer composites for personal body armor by using analytical hierarchy process”. This research work focused on selection of best candidate natural fiber from 14 alternatives by using analytical hierarchy process (AHP) and sensitivity analysis based on the personal body armour design requirements. From the analysis, naturally woven novel *Cocos nucifera* sheath (CS) has been chosen as a potential candidate natural fiber.

Chapter 5 (Objective 2: Article 2)

This chapter presents the second objective supported by the second research article entitled "Mechanical and moisture diffusion behaviour of hybrid Kevlar/*Cocos nucifera* sheath reinforced epoxy composites". This study investigated the effect of hybridizing CS with Kevlar fabric on the tensile, flexural, impact and moisture absorption behaviour of hybrid composites.

Chapter 6 (Objective 2: Article 3)

This chapter deals with the second objective supported by the third research article entitled "Improved mechanical and moisture resistant properties of woven hybrid epoxy composites by graphene nanoplatelets (GNP)". This research evaluated the effect of adding GNP on the tensile, flexural, impact and moisture absorption behaviour of Kevlar/epoxy, hybrid Kevlar/CS and CS/epoxy composites.

Chapter 7 (Objective 2: Article 4)

This chapter addresses the second objective supported by the fourth research article entitled "Improved interlaminar shear behaviour of a new hybrid Kevlar/*Cocos nucifera* sheath composites with graphene nanoplatelets modified epoxy matrix". This research investigated the effect of hybridizing Kevlar/*Cocos nucifera* sheath and the effect of adding different wt. % of Graphene nanoplatelets (GNP) on the interlaminar shear behaviour of laminated composites.

Chapter 8 (Objective 3: Article 5)

This chapter presents the third objective supported by the fifth research article entitled "Evaluation of ballistic performance of hybrid Kevlar/*Cocos nucifera* sheath reinforced epoxy composites". This research analysed the effect of hybridizing CS on the ballistic performance in terms of energy absorption and ballistic limit of Kevlar/epoxy laminated composites.

Chapter 9 (Objective 3: Article 6)

This chapter deals with the third objective supported by the sixth research article entitled "Effect of graphene nanoplatelets on the ballistic performance of hybrid Kevlar/*Cocos nucifera* sheath-reinforced epoxy composites". This research evaluated the effect of adding different wt% of GNP on the ballistic performance of Kevlar/epoxy, hybrid Kevlar/CS and CS/epoxy composites.

Chapter 10 (Objective 4: Article 7)

This chapter presents the fourth objective supported by the seventh research article entitled "Thermal degradation and viscoelastic properties of Kevlar/*Cocos nucifera* sheath reinforced epoxy hybrid composites". This study investigated the effect of adding different wt% of CS on the dynamic mechanical and thermal properties of Kevlar/epoxy composites at elevated temperature.

Chapter 11 (Objective 4: Article 8)

This chapter addresses the fourth objective supported by the eighth research article entitled "Enhanced thermal and dynamic mechanical properties of synthetic/natural hybrid composites with graphene nanoplateletes". The aim of this research work is to enhance the thermal and dynamic mechanical properties of Kevlar/*Cocos nucifera* sheath (CS) /epoxy composites with graphene nano platelets (GNP).

Chapter 12

This chapter addresses the conclusions from the individual articles and overall conclusions & future recommendations.

REFERENCES

Abali, F., Pora, A., & Shivakumar, K. (2003). Modified Short Beam Shear Test for Measurement of Interlaminar Shear Strength of Composites. *Journal of Composite Materials, 37*(5), 453-464. doi: 10.1177/0021998303037005053

Abu-Jdayil, B., Mourad, A. H., & Hassan, M. (2018). Development of polymeric heat insulators based on emirati red shale filler: Thermal and physical properties. *Polymer Composites, 39*(S3), E1463-E1473.

Ahmadi-Moghadam, B., Sharafimasooleh, M., Shadlou, S., & Taheri, F. (2015). Effect of functionalization of graphene nanoplatelets on the mechanical response of graphene/epoxy composites. *Materials & Design (1980-2015), 66*, 142-149.

Ahmed, K. S., & Vijayarangan, S. (2008). Tensile, flexural and interlaminar shear properties of woven jute and jute-glass fabric reinforced polyester composites. *Journal of materials processing technology, 207*(1-3), 330-335.

Akay, M. (1993). Aspects of dynamic mechanical analysis in polymeric composites. *composites science and technology, 47*(4), 419-423.

Al-Harbi, K. M. A.-S. (2001). Application of the AHP in project management. *International journal of project management, 19*(1), 19-27.

Al-Oqla, F. M., Salit, M. S., Ishak, M. R., & Aziz, N. A. (2015). Selecting natural fibers for bio-based materials with conflicting criteria. *American Journal of Applied Sciences, 12*(1), 64.

Al-oqla, F. M., Sapuan, S., Ishak, M. R., & Nuraini, A. (2015). Decision making model for optimal reinforcement condition of natural fiber composites. *Fibers and Polymers, 16*(1), 153-163.

Ali, M., Liu, A., Sou, H., & Chouw, N. (2012). Mechanical and dynamic properties of coconut fibre reinforced concrete. *Construction and Building Materials, 30*, 814-825.

Angrizani, C. C., Ornaghi, H. L., Zattera, A. J., & Amico, S. C. (2017). Thermal and mechanical investigation of interlaminate glass/curaua hybrid polymer composites. *Journal of natural fibers, 14*(2), 271-277.

Arab, B., Shokuhfar, A., & Ebrahimi-Nejad, S. (2012). *Glass transition temperature of cross-linked epoxy polymers: a molecular dynamics study.* Paper presented at the Proceedings of the International Conference Nanomaterials: Applications and Properties.

Asim, M., Jawaid, M., Nasir, M., & Saba, N. (2018). Effect of fiber loadings and treatment on dynamic mechanical, thermal and flammability properties of pineapple leaf fiber and kenaf phenolic composites. *Journal of Renewable Materials, 6*(4), 383-393.

Assis, F. S. d., Pereira, A. C., Filho, F. d. C. G., Lima, É. P., Monteiro, S. N., & Weber, R. P. (2018). Performance of jute non-woven mat reinforced polyester matrix composite in multilayered armor. *Journal of Materials Research and Technology, 7*(4), 535-540. doi: https://doi.org/10.1016/j.jmrt.2018.05.026

Atiqah, A., Jawaid, M., Sapuan, S., & Ishak, M. (2018a). Dynamic mechanical properties of sugar palm/glass fiber reinforced thermoplastic polyurethane hybrid composites. *Polymer Composites*. *40*,1329-1334

Atiqah, A., Jawaid, M., Sapuan, S., Ishak, M., & Alothman, O. Y. (2018b). Thermal properties of sugar palm/glass fiber reinforced thermoplastic polyurethane hybrid composites. *Composite Structures, 202*, 954-958.

Atiqah, A., Maleque, M., Jawaid, M., & Iqbal, M. (2014). Development of kenaf-glass reinforced unsaturated polyester hybrid composite for structural applications. *Composites Part B: Engineering, 56*, 68-73.

Azrin Hani Abdul, R., Roslan, A., Jaafar, M., Roslan, M. N., & Ariffin, S. (2011). *Mechanical properties evaluation of woven coir and kevlar reinforced epoxy composites.* Advanced Materials Research,*277*,36-42

Bajaj, P. (1997). Ballistic protective clothing: An overview. *Indian Journal of Fibre and Textile Research,22,*274-291

Balandin, A. A., Ghosh, S., Bao, W., Calizo, I., Teweldebrhan, D., Miao, F., & Lau, C. N. (2008). Superior thermal conductivity of single-layer graphene. *Nano Letters, 8*(3), 902-907.

Bandaru, A. K., Ahmad, S., & Bhatnagar, N. (2017). Ballistic performance of hybrid thermoplastic composite armors reinforced with Kevlar and basalt fabrics. *Composites Part A: Applied Science and Manufacturing, 97*, 151-165.

Bandaru, A. K., Patel, S., Sachan, Y., Ahmad, S., Alagirusamy, R., & Bhatnagar, N. (2016). Mechanical behavior of Kevlar/basalt reinforced polypropylene composites. *Composites Part A: Applied Science and Manufacturing, 90*, 642-652.

Bandaru, A. K., Sachan, Y., Ahmad, S., Alagirusamy, R., & Bhatnagar, N. (2017). On the mechanical response of 2D plain woven and 3D angle-interlock fabrics. *Composites Part B: Engineering, 118*, 135-148.

Benzait, Z., & Trabzon, L. (2018a). A review of recent research on materials used in polymer–matrix composites for body armor application. *Journal of Composite Materials, 52*(23), 3241-3263.

Benzait, Z., & Trabzon, L. (2018b). A review of recent research on materials used in polymer–matrix composites for body armor application. *Journal of Composite Materials*,52,3241-3263.

Bisanda, E., & Ansell, M. P. (1991). The effect of silane treatment on the mechanical and physical properties of sisal-epoxy composites. *composites science and technology, 41*(2), 165-178.

Bledzki, A., & Gassan, J. (1999). Composites reinforced with cellulose based fibres. *Progress in polymer science, 24*(2), 221-274.

Bledzki, A., Reihmane, S., & Gassan, J. (1996). Properties and modification methods for vegetable fibers for natural fiber composites. *Journal of Applied Polymer Science, 59*(8), 1329-1336.

Bogoeva-Gaceva, G., Avella, M., Malinconico, M., Buzarovska, A., Grozdanov, A., Gentile, G., & Errico, M. (2007). Natural fiber eco-composites. *Polymer Composites, 28*(1), 98-107.

Braga, R., & Magalhaes Jr, P. (2015). Analysis of the mechanical and thermal properties of jute and glass fiber as reinforcement epoxy hybrid composites. *Materials Science and Engineering: C, 56*, 269-273.

Byrd, L. W., & Birman, V. (2006). Effectiveness of z-pins in preventing delamination of co-cured composite joints on the example of a double cantilever test. *Composites Part B: Engineering, 37*(4-5), 365-378.

Candan, Z., Gardner, D. J., & Shaler, S. M. (2016). Dynamic mechanical thermal analysis (DMTA) of cellulose nanofibril/nanoclay/pMDI nanocomposites. *Composites Part B: Engineering, 90*, 126-132.

Chen, X. (Ed.). (2016). *Advanced fibrous composite materials for ballistic protection*. Woodhead Publishing.

Cavallaro, P. V. (2011). Soft body armor: an overview of materials, manufacturing, testing, and ballistic impact dynamics: Naval Undersea Warfare Center Div Newport RI.

Cecen, V., Seki, Y., Sarikanat, M., & Tavman, I. H. (2008). FTIR and SEM analysis of polyester-and epoxy-based composites manufactured by VARTM process. *Journal of Applied Polymer Science, 108*(4), 2163-2170.

Chang, C.-W., Wu, C.-R., Lin, C.-T., & Chen, H.-C. (2007). An application of AHP and sensitivity analysis for selecting the best slicing machine. *Computers & Industrial Engineering, 52*(2), 296-307.

Chaudhary, S. N., Borkar, S., & Mantha, S. (2010). Sunnhemp fiber-reinforced waste polyethylene bag composites. *Journal of Reinforced Plastics and Composites, 29*(15), 2241-2252.

Chawla, K. (2016). *Fibrous materials*: Cambridge university press.

Chee, S. S., Jawaid, M., Sultan, M., Alothman, O. Y., & Abdullah, L. C.(2019) Evaluation of the hybridization effect on the thermal and thermo-oxidative stability of bamboo/kenaf/epoxy hybrid composites. *Journal of Thermal Analysis and Calorimetry,137*, 55-63.

Cheeseman, B. A., & Bogetti, T. A. (2003). Ballistic impact into fabric and compliant composite laminates. *Composite Structures, 61*(1-2), 161-173.

Chen, H. (2014). Chemical composition and structure of natural lignocellulose *Biotechnology of lignocellulose* (pp. 25-71): Springer.

Chen, Q., Zhao, Y., Zhou, Z., Rahman, A., Wu, X.-F., Wu, W., . . . Fong, H. (2013). Fabrication and mechanical properties of hybrid multi-scale epoxy composites reinforced with conventional carbon fiber fabrics surface-attached with electrospun carbon nanofiber mats. *Composites Part B: Engineering, 44*(1), 1-7.

Chen, X., Zhu, F., & Wells, G. (2013). An analytical model for ballistic impact on textile based body armour. *Composites Part B: Engineering, 45*(1), 1508-1514.

Chen, Z., Lin, Y.-M., Rooks, M. J., & Avouris, P. (2007). Graphene nano-ribbon electronics. *Physica E: Low-dimensional Systems and Nanostructures, 40*(2), 228-232.

Cheng, F., Hu, Y., & Yuan, J. (2014). Preparation and characterization of glass fiber-coir hybrid composites by a novel and facile Prepreg/Press process. *Fibers and Polymers, 15*(8), 1715-1721.

Costa, C., Fonseca, A., Serra, A., & Coelho, J. (2016). Dynamic mechanical thermal analysis of polymer composites reinforced with natural fibers. *Polymer Reviews, 56*(2), 362-383.

da Silva Neves, A. J., & Camanho, R. (2015). The use of AHP for IT project priorization–a case study for oil & gas company. *Procedia Computer Science, 55*, 1097-1105.

Dalalah, D., Al-Oqla, F., & Hayajneh, M. (2010). Application of the Analytic Hierarchy Process (AHP) in Multi-Criteria Analysis of the Selection of

Cranes. *Jordan Journal of Mechanical & Industrial Engineering, 4*(5), 567-578.
Dang, Z.-M., Yuan, J.-K., Zha, J.-W., Zhou, T., Li, S.-T., & Hu, G.-H. (2012). Fundamentals, processes and applications of high-permittivity polymer–matrix composites. *Progress in materials science, 57*(4), 660-723.
Dassios, K. G., Musso, S., & Galiotis, C. (2012). Compressive behavior of MWCNT/epoxy composite mats. *Composites science and technology, 72*(9), 1027-1033.
de Oliveira Braga, F., Bolzan, L. T., da Luz, F. S., Lopes, P. H. L. M., Lima Jr, É. P., & Monteiro, S. N. (2017). High energy ballistic and fracture comparison between multilayered armor systems using non-woven curaua fabric composites and aramid laminates. *Journal of Materials Research and Technology, 6*(4), 417-422.
De Rosa, I. M., Dhakal, H. N., Santulli, C., Sarasini, F., & Zhang, Z. Y. (2012). Post-impact static and cyclic flexural characterisation of hemp fibre reinforced laminates. *Composites Part B: Engineering, 43*(3), 1382-1396.
Demir, H., Atikler, U., Balköse, D., & Tıhmınlıoğlu, F. (2006). The effect of fiber surface treatments on the tensile and water sorption properties of polypropylene–luffa fiber composites. *Composites Part A: Applied Science and Manufacturing, 37*(3), 447-456.
Devi, L. U., Bhagawan, S., & Thomas, S. (1997). Mechanical properties of pineapple leaf fiber-reinforced polyester composites. *Journal of Applied Polymer Science, 64*(9), 1739-1748.
Devi, L. U., Bhagawan, S., & Thomas, S. (2010). Dynamic mechanical analysis of pineapple leaf/glass hybrid fiber reinforced polyester composites. *Polymer Composites, 31*(6), 956-965.
DiBenedetto, A. (2001). Tailoring of interfaces in glass fiber reinforced polymer composites: a review. *Materials Science and Engineering: A, 302*(1), 74-82.
Du, X., Skachko, I., Barker, A., & Andrei, E. Y. (2008). Approaching ballistic transport in suspended graphene. *Nature nanotechnology, 3*(8), 491.
Dweiri, F., & Al-Oqla, F. M. (2006). Material selection using analytical hierarchy process. *International journal of computer applications in technology, 26*(4), 182-189.
Dweiri, F., Kumar, S., Khan, S. A., & Jain, V. (2016). Designing an integrated AHP based decision support system for supplier selection in automotive industry. *Expert Systems with Applications, 62*, 273-283.
Eda, G., & Chhowalla, M. (2009). Graphene-based composite thin films for electronics. *Nano Letters, 9*(2), 814-818.
Erdogan, S. A., Šaparauskas, J., & Turskis, Z. (2017). Decision making in construction management: AHP and expert choice approach. *Procedia engineering, 172*, 270-276.
Espert, A., Vilaplana, F., & Karlsson, S. (2004). Comparison of water absorption in natural cellulosic fibres from wood and one-year crops in polypropylene composites and its influence on their mechanical properties. *Composites Part A: Applied Science and Manufacturing, 35*(11), 1267-1276.

Fan, J., Wang, J., Shi, Z., Yu, S., & Yin, J. (2013). Kevlar nanofiber-functionalized multiwalled carbon nanotubes for polymer reinforcement. *Materials Chemistry and Physics, 141*(2-3), 861-868.

Fan, Z., Santare, M. H., & Advani, S. G. (2008). Interlaminar shear strength of glass fiber reinforced epoxy composites enhanced with multi-walled carbon nanotubes. *Composites Part A: Applied Science and Manufacturing, 39*(3), 540-554. doi: https://doi.org/10.1016/j.compositesa.2007.11.013

Ferry, J. D., & Ferry, J. D. (1980). *Viscoelastic properties of polymers*: John Wiley & Sons.

Flynn, J., Amiri, A., & Ulven, C. (2016). Hybridized carbon and flax fiber composites for tailored performance. *Materials & Design, 102*, 21-29.

Fouladi, M. H., Nor, M. J. M., Ayub, M., & Leman, Z. A. (2010). Utilization of coir fiber in multilayer acoustic absorption panel. *Applied Acoustics, 71*(3), 241-249.

Frankland, S., Caglar, A., Brenner, D., & Griebel, M. (2002). Molecular simulation of the influence of chemical cross-links on the shear strength of carbon nanotube− polymer interfaces. *The Journal of Physical Chemistry B, 106*(12), 3046-3048.

Frone, A. N., Nicolae, C. A., Gabor, R. A., & Panaitescu, D. M. (2015). Thermal properties of water-resistant starch–polyvinyl alcohol films modified with cellulose nanofibers. *Polymer Degradation and Stability, 121*, 385-397.

Gama, B., & Gillespie Jr, J. (2008). Punch shear based penetration model of ballistic impact of thick-section composites. *Composite Structures, 86*(4), 356-369.

Ganesh, V., & Naik, N. (1994). Thermal expansion coefficients of plain-weave fabric laminates. *Composites Science and Technology, 51*(3), 387-408.

Ganesh, V., & Naik, N. (1996). Failure behavior of plain weave fabric laminates under on-axis uniaxial tensile loading: I—laminate geometry. *Journal of Composite Materials, 30*(16), 1748-1778.

Gassan, J., & Bledzki, A. (1996). *Modification methods on nature fibers and their influence on the properties of the composites.* Paper presented at the Technical Papers Of The Annual Technical Conference-Society Of Plastics Engineers Incorporated.2552-2557

Geim, A. K., & Novoselov, K. S. (2010). The rise of graphene *Nanoscience and Technology: A Collection of Reviews from Nature Journals* (pp. 11-19): World Scientific.

Geng, Y., Liu, M. Y., Li, J., Shi, X. M., & Kim, J. K. (2008). Effects of surfactant treatment on mechanical and electrical properties of CNT/epoxy nanocomposites. *Composites Part A: Applied Science and Manufacturing, 39*(12), 1876-1883.

Gojny, F. H., Wichmann, M. H. G., Fiedler, B., Bauhofer, W., & Schulte, K. (2005). Influence of nano-modification on the mechanical and electrical properties of conventional fibre-reinforced composites. *Composites Part A: Applied Science and Manufacturing, 36*(11), 1525-1535. doi: https://doi.org/10.1016/j.compositesa.2005.02.007

Gu, J., Yang, X., Lv, Z., Li, N., Liang, C., & Zhang, Q. (2016). Functionalized graphite nanoplatelets/epoxy resin nanocomposites with high thermal conductivity. *International Journal of Heat and Mass Transfer, 92*, 15-22.

Hadden, C. M., Klimek-McDonald, D. R., Pineda, E. J., King, J. A., Reichanadter, A. M., Miskioglu, I.,Odegard, G. M. (2015). Mechanical properties of graphene nanoplatelet/carbon fiber/epoxy hybrid composites: Multiscale modeling and experiments. *Carbon, 95*, 100-112.

Hambali, A., Sapuan, S., Ismail, N., & Nukman, Y. (2010). Material selection of polymeric composite automotive bumper beam using analytical hierarchy process. *Journal of Central South University of Technology, 17*(2), 244-256.

Hameed, N., Sreekumar, P., Francis, B., Yang, W., & Thomas, S. (2007). Morphology, dynamic mechanical and thermal studies on poly (styrene-co-acrylonitrile) modified epoxy resin/glass fibre composites. *Composites Part A: Applied Science and Manufacturing, 38*(12), 2422-2432.

Hani, A., Roslan, A., Mariatti, J., & Maziah, M. (2012). *Body armor technology: a review of materials, construction techniques and enhancement of ballistic energy absorption.* Advanced Materials Research.*488*,806-812

Hani, A. A., Azman, N., Ahmad, R., Mariatti, M., Roslan, M., & Marsi, N. (2016). *Ballistic Impact Response of Woven Hybrid Coir/Kevlar Laminated Composites.* MATEC Web of Conferences.

Haque, M. M., Hasan, M., Islam, M. S., & Ali, M. E. (2009). Physico-mechanical properties of chemically treated palm and coir fiber reinforced polypropylene composites. *Bioresource technology, 100*(20), 4903-4906.

Hashmi, S., Naik, A., Chand, N., Sharma, J., & Sharma, P. (2011). Development of environment friendly hybrid layered sisal–glass–epoxy composites. *Composite Interfaces, 18*(8), 671-683.

Holbery, J., & Houston, D. (2006). Natural-fiber-reinforced polymer composites in automotive applications. *Jom, 58*(11), 80-86.

Hong, C.-E., Lee, J.-H., Kalappa, P., & Advani, S. G. (2007). Effects of oxidative conditions on properties of multi-walled carbon nanotubes in polymer nanocomposites. *composites science and technology, 67*(6), 1027-1034.

Hossain, M. K., Chowdhury, M. M. R., & Bolden, N. W. (2016). Processing and Performance Evaluation of Amine Functionalized Graphene Nanoplatelet Reinforced Epoxy Composites. *Journal of Materials Science and Engineering A, 6*(5-6), 117-130.

Hsieh, T., Kinloch, A., Masania, K., Taylor, A., & Sprenger, S. (2010). The mechanisms and mechanics of the toughening of epoxy polymers modified with silica nanoparticles. *Polymer, 51*(26), 6284-6294.

Hussein, M. A., Abu-Zied, B. M., & Asiri, A. M. (2018). Fabrication of EPYR/GNP/MWCNT carbon-based composite materials for promoted epoxy coating performance. *RSC Advances, 8*(42), 23555-23566.

Idicula, M., Malhotra, S., Joseph, K., & Thomas, S. (2005). Dynamic mechanical analysis of randomly oriented intimately mixed short banana/sisal hybrid fibre reinforced polyester composites. *composites science and technology, 65*(7-8), 1077-1087.

Inuwa, I., Hassan, A., & Arjmandi, R. (2016). Influence of Exfoliated Graphite Nanoplatelets on Properties of Polyethylene Terephthalate/Polypropylene Nanocomposites. *Advances in Polymer Materials and Technology*, 333.

Ishak, M., Leman, Z., Sapuan, S., Rahman, M., & Anwar, U. (2013). Chemical composition and FT-IR spectra of sugar palm (Arenga pinnata) fibers obtained from different heights. *Journal of natural fibers, 10*(2), 83-97.
Jacob, M., Francis, B., Thomas, S., & Varughese, K. (2006). Dynamical mechanical analysis of sisal/oil palm hybrid fiber-reinforced natural rubber composites. *Polymer Composites, 27*(6), 671-680.
Jain, L. K., & Mai, Y.-W. (1994). On the effect of stitching on mode I delamination toughness of laminated composites. *composites science and technology, 51*(3), 331-345.
Jambari, S., Yahya, M. Y., Abdullah, M. R., & Jawaid, M. (2017). Woven Kenaf/Kevlar Hybrid Yarn as potential fiber reinforced for anti-ballistic composite material. *Fibers and Polymers, 18*(3), 563-568.
Jappes, J. W., & Siva, I. (2011). Studies on the influence of silane treatment on mechanical properties of coconut sheath-reinforced polyester composite. *Polymer-Plastics Technology and Engineering, 50*(15), 1600-1605.
Jarukumjorn, K., & Suppakarn, N. (2009). Effect of glass fiber hybridization on properties of sisal fiber–polypropylene composites. *Composites Part B: Engineering, 40*(7), 623-627.
Jawaid, M., & Khalil, H. A. (2011). Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review. *Carbohydrate polymers, 86*(1), 1-18.
Jawaid, M., Khalil, H. A., & Alattas, O. S. (2012). Woven hybrid biocomposites: dynamic mechanical and thermal properties. *Composites Part A: Applied Science and Manufacturing, 43*(2), 288-293.
Jawaid, M., Khalil, H. A., & Bakar, A. A. (2011). Woven hybrid composites: Tensile and flexural properties of oil palm-woven jute fibres based epoxy composites. *Materials Science and Engineering: A, 528*(15), 5190-5195.
Jawaid, M., Khalil, H. A., Hassan, A., Dungani, R., & Hadiyane, A. (2013). Effect of jute fibre loading on tensile and dynamic mechanical properties of oil palm epoxy composites. *Composites Part B: Engineering, 45*(1), 619-624.
Jiang, W., Zhou, C., Han, G., Via, B., Swain, T., Fan, Z., & Liu, S. (2017). Classification and identification of plant fibrous material with different species using near infrared technique—A new way to approach determining biomass properties accurately within different species. *Frontiers in Plant Science, 7*, 2000.
Joseph, S., Appukuttan, S. P., Kenny, J. M., Puglia, D., Thomas, S., & Joseph, K. (2010). Dynamic mechanical properties of oil palm microfibril-reinforced natural rubber composites. *Journal of Applied Polymer Science, 117*(3), 1298-1308.
Joshi, S. V., Drzal, L., Mohanty, A., & Arora, S. (2004). Are natural fiber composites environmentally superior to glass fiber reinforced composites? *Composites Part A: Applied science and manufacturing, 35*(3), 371-376.
Kamar, N. T., Hossain, M. M., Khomenko, A., Haq, M., Drzal, L. T., & Loos, A. (2015). Interlaminar reinforcement of glass fiber/epoxy composites with graphene nanoplatelets. *Composites Part A: Applied Science and Manufacturing, 70*, 82-92.
Kang, C. H., Yoon, K. H., Park, Y.-B., Lee, D.-Y., & Jeong, S.-S. (2010). Properties of polypropylene composites containing aluminum/multi-

walled carbon nanotubes. *Composites Part A: Applied Science and Manufacturing, 41*(7), 919-926.
Keusch, S., & Haessler, R. (1999). Influence of surface treatment of glass fibres on the dynamic mechanical properties of epoxy resin composites. *Composites Part A: Applied science and manufacturing, 30*(8), 997-1002.
Khalil, H. A., Hanida, S., Kang, C., & Fuaad, N. N. (2007). Agro-hybrid composite: the effects on mechanical and physical properties of oil palm fiber (EFB)/glass hybrid reinforced polyester composites. *Journal of Reinforced Plastics and Composites, 26*(2), 203-218.
Khalil, H. A., Yusra, A. I., Bhat, A., & Jawaid, M. (2010). Cell wall ultrastructure, anatomy, lignin distribution, and chemical composition of Malaysian cultivated kenaf fiber. *Industrial crops and products, 31*(1), 113-121.
Kim, H.-S., Yang, H.-S., Kim, H.-J., & Park, H.-J. (2004). Thermogravimetric analysis of rice husk flour filled thermoplastic polymer composites. *Journal of Thermal Analysis and Calorimetry, 76*(2), 395-404.
King, J. A., Klimek, D. R., Miskioglu, I., & Odegard, G. M. (2013). Mechanical properties of graphene nanoplatelet/epoxy composites. *Journal of Applied Polymer Science, 128*(6), 4217-4223.
Koronis, G., Silva, A., & Foong, S. (2017). Predicting the flexural performance of woven flax reinforced epoxy composites using design of experiments. *Materials Today Communications, 13*, 317-324.
Kuilla, T., Bhadra, S., Yao, D., Kim, N. H., Bose, S., & Lee, J. H. (2010). Recent advances in graphene based polymer composites. *Progress in polymer science, 35*(11), 1350-1375.
Kumar, K. S., Siva, I., Rajini, N., Jappes, J. W., & Amico, S. (2016). Layering pattern effects on vibrational behavior of coconut sheath/banana fiber hybrid composites. *Materials & Design, 90*, 795-803.
Kumar, S. S., Duraibabu, D., & Subramanian, K. (2014). Studies on mechanical, thermal and dynamic mechanical properties of untreated (raw) and treated coconut sheath fiber reinforced epoxy composites. *Materials & Design, 59*, 63-69.
Lee, C., Wei, X., Kysar, J. W., & Hone, J. (2008). Measurement of the elastic properties and intrinsic strength of monolayer graphene. *science, 321*(5887), 385-388.
Lee, J.-H., Loya, P. E., Lou, J., & Thomas, E. L. (2014). Dynamic mechanical behavior of multilayer graphene via supersonic projectile penetration. *science, 346*(6213), 1092-1096.
Li, B., & Zhong, W.-H. (2011). Review on polymer/graphite nanoplatelet nanocomposites. *Journal of Materials Science, 46*(17), 5595-5614.
Liang, J., Xu, Y., Huang, Y., Zhang, L., Wang, Y., Ma, Y., . . . Chen, Y. (2009). Infrared-triggered actuators from graphene-based nanocomposites. *The Journal of Physical Chemistry C, 113*(22), 9921-9927.
Liu, N., Luo, F., Wu, H., Liu, Y., Zhang, C., & Chen, J. (2008). One-step ionic-liquid-assisted electrochemical synthesis of ionic-liquid-functionalized graphene sheets directly from graphite. *Advanced Functional Materials, 18*(10), 1518-1525.
Liu, P., & Strano, M. S. (2016). Toward ambient armor: can new materials change longstanding concepts of projectile protection? *Advanced Functional Materials, 26*(6), 943-954.

Loganathan, T. M., Gobalakrishnan, K., Muthaiyah, G M., Sultan, M & Jawaid, M. (Eds). (2019). Ballistic impact response of laminated hybrid composite materials *Mechanical and Physical Testing of Biocomposites, Fibre-Reinforced Composites and Hybrid Composites* (pp. 171-191): Elsevier.

Luz, F. S. d., Junior, L., Pereira, E., Louro, L. H. L., & Monteiro, S. N. (2015). Ballistic test of multilayered armor with intermediate epoxy composite reinforced with jute fabric. *Materials Research, 18*, 170-177.

Mallick, P. K. (2007). *Fiber-reinforced composites: materials, manufacturing, and design*: CRC press.

Mandal, A., & Chakrabarty, D. (2014). Studies on the mechanical, thermal, morphological and barrier properties of nanocomposites based on poly (vinyl alcohol) and nanocellulose from sugarcane bagasse. *Journal of Industrial and Engineering Chemistry, 20*(2), 462-473.

Mandal, S., & Alam, S. (2012). Dynamic mechanical analysis and morphological studies of glass/bamboo fiber reinforced unsaturated polyester resin-based hybrid composites. *Journal of Applied Polymer Science, 125*(S1), E382-E387.

Mannov, E., Schmutzler, H., Chandrasekaran, S., Viets, C., Buschhorn, S., Tölle, F., . . . Schulte, K. (2013). Improvement of compressive strength after impact in fibre reinforced polymer composites by matrix modification with thermally reduced graphene oxide. *composites science and technology, 87*, 36-41.

Mansor, M., Sapuan, S., Zainudin, E., Nuraini, A., & Hambali, A. (2013). Hybrid natural and glass fibers reinforced polymer composites material selection using Analytical Hierarchy Process for automotive brake lever design. *Materials & Design, 51*, 484-492.

Mansor, M., Sapuan, S., Zainudin, E., Nuraini, A., & Hambali, A. (2014). Conceptual design of kenaf fiber polymer composite automotive parking brake lever using integrated TRIZ–Morphological Chart–Analytic Hierarchy Process method. *Materials & Design (1980-2015), 54*, 473-482.

Mashouf Roudsari, G., Mohanty, A. K., & Misra, M. (2017). A statistical approach to develop biocomposites from epoxy resin, poly (furfuryl alcohol), poly (propylene carbonate), and biochar. *Journal of Applied Polymer Science, 134*(38).

Mavrich, A. M., Ishida, H., & Koenig, J. L. (1995). Infrared mapping of surface-modified Kevlar fiber-reinforced epoxy systems. *Applied spectroscopy, 49*(2), 149-155.

Md Shah, A. U., Sultan, M. T., & Jawaid, M. (2019). Sandwich-structured bamboo powder/glass fibre-reinforced epoxy hybrid composites–Mechanical performance in static and dynamic evaluations. *Journal of Sandwich Structures & Materials*, 1099636218822740.

Mishra, S., Mohanty, A., Drzal, L., Misra, M., Parija, S., Nayak, S., & Tripathy, S. (2003). Studies on mechanical performance of biofibre/glass reinforced polyester hybrid composites. *composites science and technology, 63*(10), 1377-1385.

Mohammed, L., Ansari, M. N., Pua, G., Jawaid, M., & Islam, M. S. (2015). A review on natural fiber reinforced polymer composite and its applications. *International Journal of Polymer Science, 2015*.243947

Monteiro, S. N., Calado, V., Rodriguez, R. J. S., & Margem, F. M. (2012). Thermogravimetric behavior of natural fibers reinforced polymer composites—An overview. *Materials Science and Engineering: A, 557*, 17-28.

Monteiro, S. N., Candido, V. S., Braga, F. O., Bolzan, L. T., Weber, R. P., & Drelich, J. W. (2016). Sugarcane bagasse waste in composites for multilayered armor. *European Polymer Journal, 78*, 173-185.

Monteiro, S. N., Lopes, F. P. D., Ferreira, A. S., & Nascimento, D. C. O. (2009). Natural-fiber polymer-matrix composites: cheaper, tougher, and environmentally friendly. *Jom, 61*(1), 17-22.

Monteiro, S. N., Milanezi, T. L., Louro, L. H. L., Lima Jr, É. P., Braga, F. O., Gomes, A. V., & Drelich, J. W. (2016). Novel ballistic ramie fabric composite competing with Kevlar™ fabric in multilayered armor. *Materials & Design, 96*, 263-269.

Moriche, R., Prolongo, S., Sánchez, M., Jiménez-Suárez, A., Sayagués, M., & Ureña, A. (2015). Morphological changes on graphene nanoplatelets induced during dispersion into an epoxy resin by different methods. *Composites Part B: Engineering, 72*, 199-205.

Mourad, A.-H., Fouad, H., & Elleithy, R. (2009). Impact of some environmental conditions on the tensile, creep-recovery, relaxation, melting and crystallinity behaviour of UHMWPE-GUR 410-medical grade. *Materials & Design, 30*(10), 4112-4119.

Mourad, A.-H. I. (2010). Thermo-mechanical characteristics of thermally aged polyethylene/polypropylene blends. *Materials & Design, 31*(2), 918-929.

Mourad, A.-H. I., & Zaaroura, N. (2018). Impact of Nanofillers Incorporation on Laminated Nanocomposites Performance. *Journal of Materials Engineering and Performance, 27*(9), 4453-4461.

Naik, N. Vadim, V. S (Ed) (2016). Ballistic impact behavior of composites: Analytical formulation *Dynamic Deformation, Damage and Fracture in Composite Materials and Structures* (pp. 425-470): Woodhead Publising

Naik, N., & Shrirao, P. (2004). Composite structures under ballistic impact. *Composite Structures, 66*(1-4), 579-590.

Nair, K. M., Thomas, S., & Groeninckx, G. (2001). Thermal and dynamic mechanical analysis of polystyrene composites reinforced with short sisal fibres. *composites science and technology, 61*(16), 2519-2529.

Nascimento, L. F. C., Louro, L. H. L., Monteiro, S. N., Gomes, A. V., Marçal, R. L. S. B., Júnior, L., Margem, J. I. (2017). Ballistic Performance of Mallow and Jute Natural Fabrics Reinforced Epoxy Composites in Multilayered Armor. *Materials Research*(AHEAD), *20*,399-403.

Nayak, S. K. (2009). Degradation and flammability behavior of PP/banana and glass fiber-based hybrid composites. *International Journal of Plastics Technology, 13*(1), 47.

Nayak, S. K., & Mohanty, S. (2010). Sisal glass fiber reinforced PP hybrid composites: effect of MAPP on the dynamic mechanical and thermal properties. *Journal of Reinforced Plastics and Composites, 29*(10), 1551-1568.

Nayak, S. K., Mohanty, S., & Samal, S. K. (2009). Influence of short bamboo/glass fiber on the thermal, dynamic mechanical and rheological properties of polypropylene hybrid composites. *Materials Science and Engineering: A, 523*(1-2), 32-38.

Nurul Hidayah, I., Nuur Syuhada, D., Abdul Khalil, H. P. S., Ishak, Z. A. M., & Mariatti, M. (2019). Enhanced performance of lightweight kenaf-based hierarchical composite laminates with embedded carbon nanotubes. *Materials & Design, 171*, 107710. doi: https://doi.org/10.1016/j.matdes.2019.107710

Ornaghi Jr, H. L., da Silva, H. S. P., Zattera, A. J., & Amico, S. C. (2011). Hybridization effect on the mechanical and dynamic mechanical properties of curaua composites. *Materials Science and Engineering: A, 528*(24), 7285-7289.

Pandey, K. (1999). A study of chemical structure of soft and hardwood and wood polymers by FTIR spectroscopy. *Journal of Applied Polymer Science, 71*(12), 1969-1975.

Pandya, K., Akella, K., Joshi, M., & Naik, N. (2012). Ballistic impact behavior of carbon nanotube and nanosilica dispersed resin and composites. *Journal of Applied Physics, 112*(11), 113522.

Pang, H., Bai, R., Shao, Q., Gao, Y., Li, A., & Tang, Z. (2015). A novel Ag catalyzation process using swelling impregnation method for electroless Ni deposition on Kevlar® fiber. *Applied Surface Science, 359*, 280-287.

Panthapulakkal, S., & Sain, M. (2007). Injection-molded short hemp fiber/glass fiber-reinforced polypropylene hybrid composites—Mechanical, water absorption and thermal properties. *Journal of Applied Polymer Science, 103*(4), 2432-2441.

Park, R., & Jang, J. (1998). Stacking sequence effect of aramid–UHMPE hybrid composites by flexural test method: Material properties. *Polymer Testing, 16*(6), 549-562.

Park, S., & Ruoff, R. S. (2009). Chemical methods for the production of graphenes. *Nature nanotechnology, 4*(4), 217.

Partridge, I. K., & Cartié, D. D. R. (2005). Delamination resistant laminates by Z-Fiber® pinning: Part I manufacture and fracture performance. *Composites Part A: Applied Science and Manufacturing, 36*(1), 55-64. doi: https://doi.org/10.1016/j.compositesa.2004.06.029

Pathak, A. K., Borah, M., Gupta, A., Yokozeki, T., & Dhakate, S. R. (2016). Improved mechanical properties of carbon fiber/graphene oxide-epoxy hybrid composites. *composites science and technology, 135*, 28-38.

Pedrazzoli, D., & Pegoretti, A. (2014). Hybridization of short glass fiber polypropylene composites with nanosilica and graphite nanoplatelets. *Journal of Reinforced Plastics and Composites, 33*(18), 1682-1695.

Pothan, L., Cherian, B., Anandakutty, B., & Thomas, S. (2007). Effect of layering pattern on the water absorption behavior of banana glass hybrid composites. *Journal of Applied Polymer Science, 105*(5), 2540-2548.

Pothan, L. A., Oommen, Z., & Thomas, S. (2003). Dynamic mechanical analysis of banana fiber reinforced polyester composites. *composites science and technology, 63*(2), 283-293.

Prolongo, S., Jiménez-Suárez, A., Moriche, R., & Ureña, A. (2018). Influence of Thickness and Lateral Size of Graphene Nanoplatelets on Water Uptake in Epoxy/Graphene Nanocomposites. *Applied Sciences, 8*(9), 1550.

Radif, Z. S., Ali, A., & Abdan, K. (2011). Development of a green combat armour from rame-Kevlar-polyester composite. *Pertanika Journal of Science and Technology, 19*(2), 339-348.

Rafiee, M. A., Rafiee, J., Srivastava, I., Wang, Z., Song, H., Yu, Z. Z., & Koratkar, N. (2010). Fracture and fatigue in graphene nanocomposites. *small, 6*(2), 179-183.
Rafiee, M. A., Rafiee, J., Wang, Z., Song, H., Yu, Z.-Z., & Koratkar, N. (2009). Enhanced mechanical properties of nanocomposites at low graphene content. *ACS nano, 3*(12), 3884-3890.
Rajini, N., Jappes, J. W., Jeyaraj, P., Rajakarunakaran, S., & Bennet, C. (2013). Effect of montmorillonite nanoclay on temperature dependence mechanical properties of naturally woven coconut sheath/polyester composite. *Journal of Reinforced Plastics and Composites, 32*(11), 811-822.
Rajini, N., Jappes, J. W., Rajakarunakaran, S., & Jeyaraj, P. (2012). Mechanical and free vibration properties of montmorillonite clay dispersed with naturally woven coconut sheath composite. *Journal of Reinforced Plastics and Composites, 31*(20), 1364-1376.
Rajini, N., Jappes, J. W., Rajakarunakaran, S., & Jeyaraj, P. (2013). Dynamic mechanical analysis and free vibration behavior in chemical modifications of coconut sheath/nano-clay reinforced hybrid polyester composite. *Journal of Composite Materials, 47*(24), 3105-3121.
Ramanathan, T., Abdala, A., Stankovich, S., Dikin, D., Herrera-Alonso, M., Piner, R., Ruoff, R. (2008). Functionalized graphene sheets for polymer nanocomposites. *Nature nanotechnology, 3*(6), 327.
Rasana, N., Jayanarayanan, K., Deeraj, B., & Joseph, K. (2019). The thermal degradation and dynamic mechanical properties modeling of MWCNT/glass fiber multiscale filler reinforced polypropylene composites. *composites science and technology, 169*, 249-259.
Rashid, K., Razzaq, A., Ahmad, M., Rashid, T., & Tariq, S. (2017). Experimental and analytical selection of sustainable recycled concrete with ceramic waste aggregate. *Construction and Building Materials, 154*, 829-840.
Ratna, D. (2009). *Handbook of thermoset resins*: ISmithers Shawbury, UK.
Reddy, K. O., Reddy, G. S., Maheswari, C. U., Rajulu, A. V., & Rao, K. M. (2010a). Structural characterization of coconut tree leaf sheath fiber reinforcement. *Journal of Forestry Research, 21*(1), 53-58.
Reddy, K. O., Reddy, G. S., Maheswari, C. U., Rajulu, A. V., & Rao, K. M. (Writers). (2010b). Structural characterization of coconut tree leaf sheath fiber reinforcement, *Journal of Forestry Research*.
Riewald, P., Folgar, F., Yang, H., & Shaughnessy, W. (1991). Lightweight helmet from a new aramid fiber. *Advanced Materials/Affordable Processes., 23*, 684-695.
Risby, M., Wong, S., Hamouda, A., Khairul, A., & Elsadig, M. (2008). Ballistic Performance of Coconut Shell Powder/Twaron Fabricagainst Non-armour Piercing Projectiles. *Defence Science Journal, 58*(2), 248-263.
Roe, P., & Ansell, M. P. (1985). Jute-reinforced polyester composites. *Journal of Materials Science, 20*(11), 4015-4020.
Rohen, L. A., Margem, F. M., Monteiro, S. N., Vieira, C. M. F., Madeira de Araujo, B., & Lima, E. S. (2015). Ballistic efficiency of an individual epoxy composite reinforced with sisal fibers in multilayered armor. *Materials Research, 18*, 55-62.

Saba, N., Jawaid, M., Alothman, O. Y., & Paridah, M. (2016). A review on dynamic mechanical properties of natural fibre reinforced polymer composites. *Construction and Building Materials, 106*, 149-159.
Saba, N., Mohammad, F., Pervaiz, M., Jawaid, M., Alothman, O., & Sain, M. (2017). Mechanical, morphological and structural properties of cellulose nanofibers reinforced epoxy composites. *International journal of biological macromolecules, 97*, 190-200.
Saba, N., Safwan, A., Sanyang, M., Mohammad, F., Pervaiz, M., Jawaid, M., . . . Sain, M. (2017). Thermal and dynamic mechanical properties of cellulose nanofibers reinforced epoxy composites. *International journal of biological macromolecules, 102*, 822-828.
Safri, S. N. A., Sultan, M. T. H., Jawaid, M., & Jayakrishna, K. (2018). Impact behaviour of hybrid composites for structural applications: A review. *Composites Part B: Engineering, 133*, 112-121.
Saheb, D. N., & Jog, J. P. (1999). Natural fiber polymer composites: a review. *Advances in Polymer Technology: Journal of the Polymer Processing Institute, 18*(4), 351-363.
Salman, S. D., Leman, Z., Sultan, M. T., Ishak, M. R., & Cardona, F. (2016). Ballistic impact resistance of plain woven kenaf/aramid reinforced polyvinyl butyral laminated hybrid composite. *BioResources, 11*(3), 7282-7295.
Samal, S. K., Mohanty, S., & Nayak, S. K. (2009). Polypropylene—bamboo/glass fiber hybrid composites: fabrication and analysis of mechanical, morphological, thermal, and dynamic mechanical behavior. *Journal of Reinforced Plastics and Composites, 28*(22), 2729-2747.
Sanjay, M., Madhu, P., Jawaid, M., Senthamaraikannan, P., Senthil, S., & Pradeep, S. (2018). Characterization and properties of natural fiber polymer composites: A comprehensive review. *Journal of Cleaner Production, 172*, 566-581.
Sapuan, S., Kho, J., Zainudin, E., Leman, Z., Ali, B., & Hambali, A. (2011). Materials selection for natural fiber reinforced polymer composites using analytical hierarchy process. *18(*4),255-267
Sathishkumar, T., Naveen, J., & Satheeshkumar, S. (2014a). Hybrid fiber reinforced polymer composites–a review. *Journal of Reinforced Plastics and Composites, 33*(5), 454-471.
Sathishkumar, T., Naveen, J. a., & Satheeshkumar, S. (2014b). Hybrid fiber reinforced polymer composites–a review. *Journal of Reinforced Plastics and Composites, 33*(5), 454-471.
Saw, S. K., & Datta, C. (2009). Thermo mechanical properties of jute/bagasse hybrid fibre reinforced epoxy thermoset composites. *BioResources, 4*(4), 1455-1475.
Schilde, C., Schlömann, M., Overbeck, A., Linke, S., & Kwade, A. (2015). Thermal, mechanical and electrical properties of highly loaded CNT-epoxy composites–A model for the electric conductivity. *composites science and technology, 117*, 183-190.
Schlesing, W., Buhk, M., & Osterhold, M. (2004). Dynamic mechanical analysis in coatings industry. *Progress in organic coatings, 49*(3), 197-208.
Schuster, D. (1970). Ballistic impact on composites. *WIT Transactions on Engineering Sciences, 4*.

Sen, A., & Kumar, S. (2010). Coir-fiber-based fire retardant nano filler for epoxy composites. *Journal of Thermal Analysis and Calorimetry, 101*(1), 265-271.
Senthilkumar, K., Saba, N., Rajini, N., Chandrasekar, M., Jawaid, M., Siengchin, S., & Alotman, O. Y. (2018). Mechanical properties evaluation of sisal fibre reinforced polymer composites: a review. *Construction and Building Materials, 174*, 713-729.
Shah, D. U., Schubel, P. J., & Clifford, M. J. (2013). Can flax replace E-glass in structural composites? A small wind turbine blade case study. *Composites Part B: Engineering, 52*, 172-181.
Shembekar, P., & Naik, N. (1992). Elastic behavior of woven fabric composites: II—Laminate analysis. *Journal of Composite Materials, 26*(15), 2226-2246.
Siddiqui, N. A., Woo, R. S. C., Kim, J.-K., Leung, C. C. K., & Munir, A. (2007). Mode I interlaminar fracture behavior and mechanical properties of CFRPs with nanoclay-filled epoxy matrix. *Composites Part A: Applied Science and Manufacturing, 38*(2), 449-460. doi: https://doi.org/10.1016/j.compositesa.2006.03.001
Singh, S., Srivastava, V., & Prakash, R. (2015). Influences of carbon nanofillers on mechanical performance of epoxy resin polymer. *Applied Nanoscience, 5*(3), 305-313.
Siva, I., Jappes, J. T. W., & Suresha, B. (2012). Investigation on mechanical and tribological behavior of naturally woven coconut sheath-reinforced polymer composites. *Polymer Composites, 33*(5), 723-732.
Spitalsky, Z., Tasis, D., Papagelis, K., & Galiotis, C. (2010). Carbon nanotube–polymer composites: chemistry, processing, mechanical and electrical properties. *Progress in polymer science, 35*(3), 357-401.
Sreekala, M., Thomas, S., & Groeninckx, G. (2005). Dynamic mechanical properties of oil palm fiber/phenol formaldehyde and oil palm fiber/glass hybrid phenol formaldehyde composites. *Polymer Composites, 26*(3), 388-400.
Standard, N. (2008). Ballistic Resistance of Body Armor NIJ Standard-0101.06. *US US Department of Justice, Office of Justice Programs, National Institute of Justice*.
Stankovich, S., Dikin, D. A., Dommett, G. H., Kohlhaas, K. M., Zimney, E. J., Stach, E. A.,Ruoff, R. S. (2006). Graphene-based composite materials. *nature, 442*(7100), 282.
Starkova, O., Buschhorn, S., Mannov, E., Schulte, K., & Aniskevich, A. (2013). Water transport in epoxy/MWCNT composites. *European Polymer Journal, 49*(8), 2138-2148.
Starkova, O., Buschhorn, S. T., Mannov, E., Schulte, K., & Aniskevich, A. (2013). Water transport in epoxy/MWCNT composites. *European Polymer Journal, 49*(8), 2138-2148. doi: https://doi.org/10.1016/j.eurpolymj.2013.05.010
Starkova, O., Chandrasekaran, S., Prado, L., Tölle, F., Mülhaupt, R., & Schulte, K. (2013). Hydrothermally resistant thermally reduced graphene oxide and multi-wall carbon nanotube based epoxy nanocomposites. *Polymer Degradation and Stability, 98*(2), 519-
Szakács, J., & Mészáros, L. (2018). Synergistic effects of carbon nanotubes on the mechanical properties of basalt and carbon fiber-reinforced

polyamide 6 hybrid composites. *Journal of Thermoplastic Composite Materials, 31*(4), 553-571.

Tang, L.-C., Wan, Y.-J., Yan, D., Pei, Y.-B., Zhao, L., Li, Y.-B., . . . Lai, G.-Q. (2013). The effect of graphene dispersion on the mechanical properties of graphene/epoxy composites. *Carbon, 60*, 16-27.

Tsita, K. G., & Pilavachi, P. A. (2012). Evaluation of alternative fuels for the Greek road transport sector using the analytic hierarchy process. *Energy Policy, 48*, 677-686. doi: https://doi.org/10.1016/j.enpol.2012.05.079

Umboh, M. K., Adachi, T., Oishi, K., Higuchi, M., & Major, Z. (2013). Mechanical properties of nano-silica particulate-reinforced epoxy composites considered in terms of crosslinking effect in matrix resins. *Journal of Materials Science, 48*(15), 5148-5156.

Vallés, C., Beckert, F., Burk, L., Mülhaupt, R., Young, R. J., & Kinloch, I. A. (2016). Effect of the C/O ratio in graphene oxide materials on the reinforcement of epoxy-based nanocomposites. *Journal of Polymer Science Part B: Polymer Physics, 54*(2), 281-291.

Venkateshwaran, N., & Elayaperumal, A. (2010). Banana fiber reinforced polymer composites-a review. *Journal of Reinforced Plastics and Composites, 29*(15), 2387-2396.

Wambua, P., Ivens, J., & Verpoest, I. (2003). Natural fibres: can they replace glass in fibre reinforced plastics? *composites science and technology, 63*(9), 1259-1264. doi: https://doi.org/10.1016/S0266-3538(03)00096-4

Wambua, P., Vangrimde, B., Lomov, S., & Verpoest, I. (2007). The response of natural fibre composites to ballistic impact by fragment simulating projectiles. *Composite Structures, 77*(2), 232-240.

Wang, F., Drzal, L. T., Qin, Y., & Huang, Z. (2015). Mechanical properties and thermal conductivity of graphene nanoplatelet/epoxy composites. *Journal of Materials Science, 50*(3), 1082-1093.

Wang, F., Drzal, L. T., Qin, Y., & Huang, Z. (2016a). Enhancement of fracture toughness, mechanical and thermal properties of rubber/epoxy composites by incorporation of graphene nanoplatelets. *Composites Part A: Applied Science and Manufacturing, 87*, 10-22.

Wang, F., Drzal, L. T., Qin, Y., & Huang, Z. (2016b). Size effect of graphene nanoplatelets on the morphology and mechanical behavior of glass fiber/epoxy composites. *Journal of Materials Science, 51*(7), 3337-3348.

Wang, L., Hong, J., & Chen, G. (2010). Comparison study of graphite nanosheets and carbon black as fillers for high density polyethylene. *Polymer Engineering & Science, 50*(11), 2176-2181.

Wu, G.-m., Liu, D., Liu, G.-f., Chen, J., Huo, S.-p., & Kong, Z.-w. (2015). Thermoset nanocomposites from waterborne bio-based epoxy resin and cellulose nanowhiskers. *Carbohydrate polymers, 127*, 229-235.

Xia, T., Zeng, D., Li, Z., Young, R. J., Vallés, C., & Kinloch, I. A. (2018). Electrically conductive GNP/epoxy composites for out-of-autoclave thermoset curing through Joule heating. *composites science and technology, 164*, 304-312.

Yahaya, R., Sapuan, S., Jawaid, M., Leman, Z., & Zainudin, E. (2014). Mechanical performance of woven kenaf-Kevlar hybrid composites. *Journal of Reinforced Plastics and Composites, 33*(24), 2242-2254.

Yahaya, R., Sapuan, S., Jawaid, M., Leman, Z., & Zainudin, E. (2015a). Effect of layering sequence and chemical treatment on the mechanical properties of woven kenaf–aramid hybrid laminated composites. *Materials & Design, 67*, 173-179.

Yahaya, R., Sapuan, S., Jawaid, M., Leman, Z., & Zainudin, E. (2015b). *Effect of moisture absorption on mechanical properties of natural fibre hybrid composite.* Paper presented at the Proceedings of the 13th International Conference on Environment, Ecosystems and Development, Kuala Lumpur, Malaysia.

Yahaya, R., Sapuan, S., Jawaid, M., Leman, Z., & Zainudin, E. (2015c). *Effect of moisture absorption on mechanical properties of natural fibre hybrid composite.* Paper presented at the Proceedings of the 13th International Conference on Environment, Ecosystems and Development (EED'15), ISBN.

Yahaya, R., Sapuan, S., Jawaid, M., Leman, Z., & Zainudin, E. (2015d). Effects of kenaf contents and fiber orientation on physical, mechanical, and morphological properties of hybrid laminated composites for vehicle spall liners. *Polymer Composites, 36*(8), 1469-1476.

Yahaya, R., Sapuan, S., Jawaid, M., Leman, Z., & Zainudin, E. (2016a). Effect of fibre orientations on the mechanical properties of kenaf–aramid hybrid composites for spall-liner application. *Defence Technology, 12*(1), 52-58.

Yahaya, R., Sapuan, S., Jawaid, M., Leman, Z., & Zainudin, E. (2016b). *Effect of moisture absorption on mechanical properties of natural fibre hybrid composite.* Paper presented at the Proceedings of the 13th International Conference on Environment, Ecosystems and Development (EED'15), ISBN.

Yahaya, R., Sapuan, S., Jawaid, M., Leman, Z., & Zainudin, E. (2016c). Investigating ballistic impact properties of woven kenaf-aramid hybrid composites. *Fibers and Polymers, 17*(2), 275-281.

Yahaya, R., Sapuan, S., Jawaid, M., Leman, Z., & Zainudin, E. (2016d). Measurement of ballistic impact properties of woven kenaf–aramid hybrid composites. *Measurement, 77*, 335-343.

Yahaya, R., Sapuan, S., Leman, Z., & Zainudin, E. (2014). *Selection of natural fibre for hybrid laminated composites vehicle spall liners using analytical hierarchy process (AHP).* Applied Mechanics and Materials.*564*,400-405

Yilmazcoban, I., & Doner, S. (2016). Ballistic Protection Evaluation of Sequencing the Composite Material Sandwich Panels for the Reliable Combination of Armor Layers. *Acta Physica Polonica, A., 130*(1).

Young, R. A. (2007). Wettability of wood pulp fibers: Applicability of methodology. *Wood and Fiber Science, 8*(2), 120-128.

Zaman, I., Phan, T. T., Kuan, H.-C., Meng, Q., La, L. T. B., Luong, L., . . . Ma, J. (2011). Epoxy/graphene platelets nanocomposites with two levels of interface strength. *Polymer, 52*(7), 1603-1611.

Zhang, G., Wang, F., Dai, J., & Huang, Z. (2016). Effect of functionalization of graphene nanoplatelets on the mechanical and thermal properties of silicone rubber composites. *Materials, 9*(2), 92.

Zhang, J., Ju, S., Jiang, D., & Peng, H.-X. (2013). Reducing dispersity of mechanical properties of carbon fiber/epoxy composites by introducing

multi-walled carbon nanotubes. *Composites Part B: Engineering, 54*, 371-376.
Zhong, L. X., Fu, S. Y., Zhou, X. S., & Zhan, H. Y. (2011). Effect of surface microfibrillation of sisal fibre on the mechanical properties of sisal/aramid fibre hybrid composites. *Composites Part A: Applied Science and Manufacturing, 42*(3), 244-252.
Zhou, X.-y., Zheng, F., Li, H.-g., & Lu, C.-l. (2010). An environment-friendly thermal insulation material from cotton stalk fibers. *Energy and Buildings, 42*(7), 1070-1074.
Zhou, Y., Hou, J., Gong, X., & Yang, D. (2017). Hybrid panels from woven Kevlar® and Dyneema® fabrics against ballistic impact with wearing flexibility. *The Journal of The Textile Institute*, 1-8.
Zhou, Y., Hou, J., Gong, X., & Yang, D. (2018). Hybrid panels from woven Kevlar® and Dyneema® fabrics against ballistic impact with wearing flexibility. *The journal of the Textile Institute, 109*(8), 1027-1034.
Zhou, Y., Pervin, F., Rangari, V. K., & Jeelani, S. (2006). Fabrication and evaluation of carbon nano fiber filled carbon/epoxy composite. *Materials Science and Engineering: A, 426*(1), 221-228. doi: https://doi.org/10.1016/j.msea.2006.04.031
Zhu, J., Zhu, H., Njuguna, J., & Abhyankar, H. (2013). Recent development of flax fibres and their reinforced composites based on different polymeric matrices. *Materials, 6*(11), 5171-5198.

BIODATA OF STUDENT

The student Naveen Jesu Arockiam was born on 26 th July 1991 in Tamilnadu, India. His educational journey started at St. Antony's higher secondary School, Kosavapatty, Dindigul, where he completed his high school education in 2006. He secured district rank and school topper in the high school level examinations conducted by State board of Tamilnadu. Later, he continued his higher secondary education at M.S.P.S. Memorial higher secondary school, Dindigul and completed his school education in 2008. He has completed his Bachelor's degree in Mechanical Engineering with Distinction from Anna University in 2012. Then, he finished his Master's degree in Engineering Design with Gold Medal from Kongu Engineering College, Anna University in 2014. Thereafter, he started his teaching career as an Assistant Professor at Mepco Schlenk Engineering College, India (2014-2017). During his tenure at Mepco Schlenk Engineering College, he received Faculty Publication awards and under his guidance the UG students received Best Project awards. In 2017, he started his PhD study in the field of Mechanical Engineering at Faculty of Engineering, University Putra Malaysia. During his PhD, he secured 3rd place in the 3MT (3 minutes thesis) completion held at Faculty of Engineering, UPM and received Poster award in the Safe bio pack Conference 2018.

LIST OF PUBLICATIONS

Journal Articles

Naveen, J., Jawaid, M., Zainudin, E., Sultan, M. T., & Yahaya, R. B. (2018). Selection of natural fiber for hybrid Kevlar/natural fiber reinforced polymer composites for personal body armour by using analytical hierarchy process. *Frontiers in Materials, 5*. (Q2)

Naveen, J., Jawaid, M., Zainudin, E., Sultan, M., & Yahaya, R. (2019). Mechanical and moisture diffusion behaviour of hybrid Kevlar/Cocos nucifera sheath reinforced epoxy composites. *Journal of Materials Research and Technology, 8*(1), 1308-1318. (Q1)

Naveen, J., Jawaid, M., Zainudin, E. S., Thariq Hameed Sultan, M., & Yahaya, R. (2019). Improved Mechanical and Moisture-Resistant Properties of Woven Hybrid Epoxy Composites by Graphene Nanoplatelets (GNP). *Materials, 12*(8), 1249. (Q2)

Naveen, J., Jawaid, M., Zainudin, E., Sultan, M. T., & Yahaya, R. (2019b). Improved Interlaminar Shear Behaviour of a New Hybrid Kevlar/Cocos Nucifera Sheath Composites with Graphene Nanoplatelets Modified Epoxy Matrix. *Fibers and Polymers, 20*(8), 1749-1753. (Q1)

Naveen, J., Jawaid, M., Zainudin, E., Sultan, M. T., & Yahaya, R. (2018). Evaluation of ballistic performance of hybrid Kevlar®/Cocos nucifera sheath reinforced epoxy composites. *The journal of the Textile Institute*, 1-11. (Q2)

Naveen, J., Jawaid, M., Zainudin, E., Sultan, M. T., & Yahaya, R. (2019a). Effect of graphene nanoplatelets on the ballistic performance of hybrid Kevlar/Cocos nucifera sheath-reinforced epoxy composites. *Textile Research Journal*, 0040517519833970. (Q1)

Naveen, J., Jawaid, M., Zainudin, E., Sultan, M. T., Yahaya, R., & Majid, M. A. (2019). Thermal degradation and viscoelastic properties of Kevlar/Cocos nucifera sheath reinforced epoxy hybrid composites. *Composite Structures*, 219,194-202 (Q1)

Naveen, J., Jawaid, M., Zainudin, E. S., Thariq Hameed Sultan, M., & Yahaya, R. (2019). Enhanced Thermal and Dynamic Mechanical Properties of Synthetic/Natural Hybrid Composites with Graphene Nanoplateletes. *Polymers, 11*(7), 1085. (Q1)

Proceedings /Conference

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