TEMPERATURE EFFECT ON THE LOW-VELOCITY IMPACT CHARACTERISTICS OF GLASS LAMINATED ALUMINIUM REINFORCED EPOXY PANELS

CHOW ZHEN PEI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy

School of Mechanical Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

APRIL 2022

DEDICATION

This thesis is dedicated to my father, who taught me the importance of purpose and reasoning in the pursuit of knowledge, and to believe in myself. It is also dedicated to my mother, who taught me to have perseverance, determination and gave me endless support when I needed. To my brothers who gave me advices that helped me through difficult challenges. To my friends who provided encouragement and listened to my problems.

ACKNOWLEDGEMENT

First and foremost, I would like to express my sincere gratitude towards my main supervisor, Associate Prof. Ir. Ts. Dr. Zaini Ahmad for his expertise in guidance, giving advises and critics that helped me grow and improve. I am also very grateful towards my co-supervisor, Dr Wong King Jye for his patience and eagerness in helping and guiding me. Thanks to both my supervisors for contributing their precious time and efforts, for their motivation, support and understanding throughout my research work. Without their persistent supervision and support, I would not be able to complete my research and thesis.

I would like to thank Universiti Teknologi Malaysia (UTM) for the facilities, equipment and funds given that helped my research work. Thank the UTM staffs that provided their assistance during my experimental tests.

I am deeply appreciative towards my fellow colleagues in Computational Solid Mechanics (CSM) laboratory that aided and supported me. They provided me insightful advice for my research, assistance during experimental testing and improvement ideas for my simulation modelling. Regrettably, I am unable to mention all their names due to the limited space.

I would also like to extend my gratitude towards my friends, including Mahzan, Saied, Chiang, Salman, Izzuddin, Amirul and Syed that spend their time aiding me when I reached out to them and supported me when I require motivation.

ABSTRACT

Applications of fibre metal laminates (FML) in aircraft structures involve in-service temperatures higher than 30°C up to well above 100°C. Such high temperatures could affect the FML performance. Hence, there is a need to investigate temperature effect towards the low-velocity impact response of FMLs. The purpose of this study was to evaluate the influence of increased temperature from 30 to 110°C towards the impact response of FMLs. Experimental trials were conducted at 30, 70 and 110°C to extract temperature-dependent properties of glass fibre reinforced polymer (GFRP) composite and interlaminar delamination of GFRP laminated aluminium. The experimental results obtained from the quasi-static tests at 30, 70 and 110°C and low-velocity impact tests at various impact energies were used to validate the numerical models. Explicit nonlinear code LS-DYNA was subsequently employed to develop the finite element (FE) model of the FMLs. Johnson-Cook model, Chang-Chang failure criteria and cohesive zone models were applied to simulate aluminium, GFRP and delamination, respectively. The Mode-I and Mode-II delamination and quasi-static perforation of FMLs at elevated temperatures were modelled and validated. After which, combined analysis of impact energy levels and temperatures were carried out by employing the FE quarter model. A modified property degradation model was also utilised to obtain properties at 50 and 70°C effectively with a single fitting parameter. Using the validated FE model, parametric studies were carried out to investigate the effects of varying geometrical parameters at elevated temperature. The results indicated that an increase in temperature significantly affects the low-velocity impact response and impact resistance of FMLs. Increase in temperature degrades the GFRP and GFRP/aluminium interface by a larger degree as compared to aluminium. The degradation of FMLs is progressive such that it is less significant from 30 to 70°C and more severe from 70 to 110°C. Hence, the FE modelling methodology proposed herein provides the means to simulate, predict and analyse the impact of FMLs with consideration of temperature effects. This research contributes towards the advancement of FMLs and composites for applications under high temperatures. The FE method provides a coherent and reliable way to simulate and analyse FML impact performance under different temperature conditions.

ABSTRAK

Penggunaan lapisan logam gentian (FML) dalam struktur pesawat melibatkan suhu dalam perkhidmatan yang lebih tinggi daripada 30°C sehingga melebihi 100°C. Suhu yang tinggi boleh menjejaskan prestasi FML. Oleh itu, terdapat keperluan untuk menyelidik kesan suhu terhadap tindakan hentaman halaju rendah FML. Tujuan kajian ini adalah untuk menilai pengaruh peningkatan suhu dari 30 hingga 110°C terhadap tindakan hentaman FML. Ujikaji dijalankan pada suhu 30, 70 dan 110°C untuk ekstrak sifat bersandar suhu rencam polimer bertetulang gentian kaca (GFRP) dan pelekangan antara lapisan aluminium GFRP. Keputusan ujikaji yang diperolehi daripada ujian kuasi-statik pada suhu 30, 70 dan 110°C dan ujian hentaman halaju rendah pada pelbagai tenaga hentaman digunakan untuk pengesahan model berangka. Kod tidak lelurus LS-DYNA kemudiannya digunakan untuk membangunkan model unsur terhingga (FE) FML. Model Johnson-Cook, kriteria kegagalan Chang-Chang dan model zon jeleket digunakan untuk mensimulasi masing-masing aluminium, GFRP dan lekangan. Lekangan Mod-I dan Mod-II, dan penebukan kuasi-statik FML pada suhu menaik dimodelkan dan ditentusahkan. Selepas itu, gabungan analisis aras tenaga hentaman dan suhu telah dilaksanakan menggunakan model sukuan FE. Model penurunan sifat terubahsuai juga digunakan untuk memperoleh sifat pada suhu 50 dan 70°C secara berkesan dengan parameter penentuan tunggal. Dengan menggunakan model FE yang disahkan, kajian berparameter telah dijalankan untuk mengkaji kesan perubahan parameter geometri pada suhu menaik. Keputusan menunjukkan bahawa peningkatan suhu mempengaruhi tindakan hentaman halaju rendah dan rintangan hentaman FML. Peningkatan suhu menjejaskan GFRP dan permukaan GFRP/aluminium dengan lebih ketara berbanding dengan aluminium. Penurunan prestasi FML adalah berterusan yang mana ia dilihat kurang ketara pada suhu 30 hingga 70°C, namun, didapati ketara pada suhu 70 hingga 110°C. Oleh itu, kaedah pemodelan FE yang dicadangkan menyediakan kaedah untuk simulasi, meramalkan dan menganalisis hentaman FML dengan pertimbangan kesan suhu. Penyelidikan ini menyumbang kepada pemajuan FML dan komposit untuk penggunaan pada suhu tinggi. Kaedah FE menyediakan cara yang jelas dan bolehharap untuk mensimulasi dan menganalisiskan prestasi hentaman FML pada keadaan suhu yang berbeza.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ARALL	-	Aramid Reinforced Aluminium Laminates
ASTM	-	American Society for Testing Methods
BFRP	-	Basalt Fibre Reinforced Polymer
BVID	-	Barely Visible Impact Damage
CARALL	-	Carbon Reinforced Aluminium Laminates
CFRP	-	Carbon Fibre Reinforced Polymer
DCB	-	Double Cantilever Beam
ENF	-	End Notched Flexural
ERC	-	Energy Restitution Coefficient
FE	-	Finite Element
FEM	-	Finite Element Method
FML	-	Fibre Metal Laminates
FRP	-	Fibre Reinforced Polymer
GFRP	-	Glass Fibre Reinforced Polymer
GLARE	-	Glass Laminated Aluminium Reinforced Epoxy
MVF	-	Metal Volume Fraction
PEEK		Poly-ether-ether-ketone
UD	-	Unidirectional
3D	-	Three-dimensional
T-0	-	Tensile loaded across 0° fibre direction
T-90	-	Tensile loaded across 90° fibre direction
C-0	-	Compression loaded across 0° fibre direction
C-90	-	Compression loaded across 90° fibre direction
S	-	Shear loaded across ±45° fibre direction

LIST OF SYMBOLS

T_g	-	Glass transition temperature
E_{abs}	-	Energy absorbed
E_{imp}	-	Impact energy
F_P	-	Peak load
L	-	Length
W	-	Width
h, t	-	Thickness/Height
K	-	stiffness
a_o	-	Initial crack lengths
L	-	Half-span length in ENF setup
ρ	-	Density
E	-	Young's modulus
G	-	Shear modulus
N	-	Poisson's ratio
σ_y	-	Flow stress
A, B, n	-	Johnson-Cook plastic strain material constant
C	-	Johnson-Cook strain rate effect constant
M	-	Johnson-Cook temperature effect constant
$\bar{\varepsilon}_p$	-	Effective plastic strain
$\dot{\varepsilon}$	-	Effective total strain rate
$\dot{\varepsilon}_0$	-	Quasi-static threshold rate
T	-	Effective room temperature
T_{room}	-	Room temperature
T_{melt}	-	Melting point
d_1, d_2, d_3	-	Johnson-Cook pressure effect constants
d_4	-	Johnson-Cook strain rate effect constant
d_5	-	Johnson-Cook temperature effect constant
η	-	Ratio between pressure and effective stress
e_f	-	Tensile fibre failure mode
e_c	-	Compressive fibre failure mode

e_m	-	Tensile matrix failure mode
e_d	-	Compressive matrix failure mode
σ_1	-	Effective stress tensor components in fibre direction
σ_2	-	Effective stress tensor components in matrix direction
τ_{12}	-	Effective shear tensor
X_T	-	Longitudinal tensile strength
X_C	-	Longitudinal compressive strength
Y_T	-	Transverse tensile strengths
Y_C	-	Transverse compressive strengths
S_C	-	Shear strength
E_A	-	Longitudinal Young's modulus
E_B	-	Transverse Young's modulus
$E_A{}^C$	-	Longitudinal compressive Young's modulus
$E_B{}^C$	-	Transverse compressive Young's modulus
G_{AB}	-	Shear modulus
υ_{BA}, υ_{AB}	-	In plane Poisson's ratio
B	-	Weighting factor for the shear term
ε_1	-	Axial tensile strain
ε_2	-	Lateral tensile strain
γ_{12}	-	Shear strain
G_{IC}	-	Mode-I energy release rate
σ	-	Normal direction peak traction
δ_N	-	Normal direction ultimate displacement
E_N	-	Mode-I penalty stiffness
G_{IIC}	-	Mode-II energy release rate
τ	-	Tangential direction peak traction
δ_T	-	Tangential direction ultimate displacement
E_T	-	Mode-II penalty stiffness
δ^0	-	Mixed-mode damage initiation displacement
δ_I	-	Normal separation
δ_{II}	-	Tangential separation
δ_I^0	-	Mode-I damage initiation separation
δ_{II}^0	-	Mode-II damage initiation separation

δ^F	-	Mixed-mode displacement
ψ	-	Mode mixity
XMU	-	Mixed-mode criteria stiffness
E_{IC}	-	Back-calculated Mode-I modulus
E_{IIC}	-	Back-calculated Mode-II modulus
k_I	-	Mode-I stiffness
k_{II}	-	Mode-II stiffness
Γ_I	-	Mode-I compliance
Γ_{II}	-	Mode-II compliance
$P(T)$	-	Material property at effective temperature
P_{min}	-	Material property at minimum temperature
P_{max}	-	Material property at maximum temperature
T_{min}	-	Minimum temperature
T_0, m_0	-	Mahieux model parameters
k', T_x	-	Gibson model parameters
M, N	-	Correia model parameters
Z	-	Current (modified Wong) model parameter
Φ	-	Thickness ratio between aluminium and GFRP

CHAPTER 1

INTRODUCTION

1.1 Research Background

In the recent decades, fibre metal laminates (FMLs) have become one of the major interesting research subjects. This is due to increasing requirement for superior lightweight, durable, and damage tolerant materials by particularly aircraft and aerospace industries. The substantial development of FMLs started at Fokker/TU Delft in the Netherlands, during the late 1970s. Typically, it has been suggested that thin sheets of metal alloy are laminated with alternating composite layers to form a laminated sandwich structure, as shown in Figure 1.1.

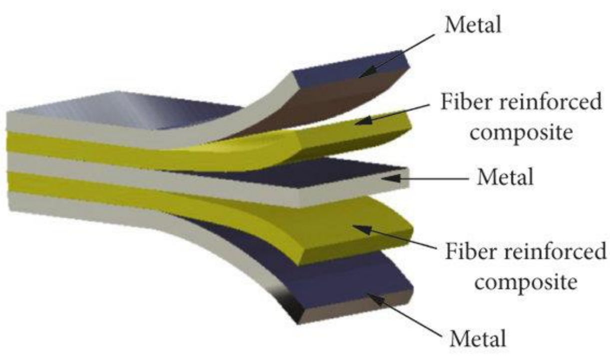

Figure 1.1 Cross-section of a typical FML [1].

The usefulness of structural materials depends on their ability to withstand damage, fracture, and failure. Damage is a broad term used to define when a material or structure loses some integrity that decreases its ability to function. Damage can range from minor to large scale impairment and can be caused by a large variety of different sources. Hence, the term ‘damage’ can be used in any part where impairment is involved. Meanwhile, fracture is more specific, which is defined by when a structure cracks, and is broken off physically, either into smaller pieces or into two separate parts. Finally, failure is the condition when a said material or structure completely loses its intended function. Therefore, damage, fracture, and failure are often related to each other. Increasing damage typically leads to failure, but do not always cause fracture, depending on the type of damage. Moreover, fracture in materials is also usually a form of damage.

FML is a better substitute material for aircraft structures. These advantages will help towards developing of much larger aircrafts such as the Airbus A3XX shown in Figure 1.2 [2]. It has been increasingly found in aeronautical, marine, and automobile applications. The glass laminate aluminium reinforced epoxy (GLARE) variant of FML has been used prevalently in aircraft structures, most notably the fuselage and tail units of Airbus A380 [2, 3].

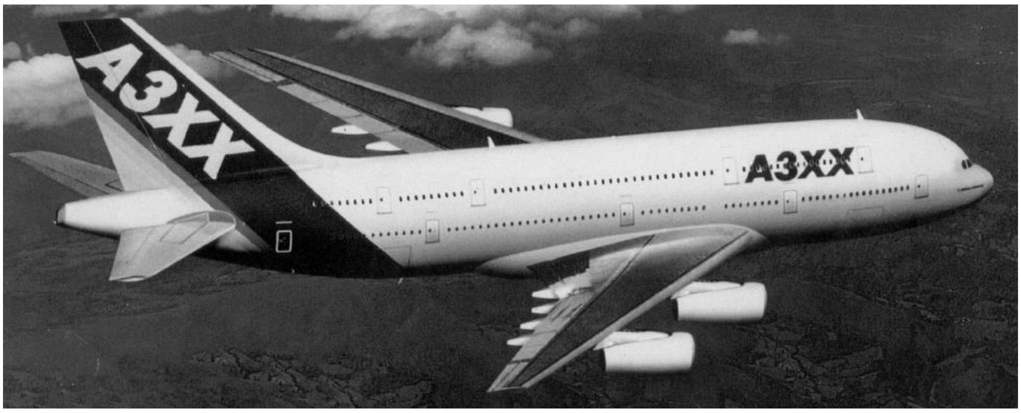

Figure 1.2 Large commercial aircraft - Airbus A3XX [2].

GLARE has the potential to be used at elevated temperatures owing to the heat resistance of the glass fibres. Previous reports indicate potential use of FMLs as fire retardants and thermal resistors [4, 5]. A vital feature of aircraft crashworthiness is to consider the fire resistance of fuselage skin materials. That is, in the event of aircraft catching fire, there is very short escape time, especially for large passenger aircrafts (>500 passengers). There is a possibility to expand the use of FML into other applications that requires energy absorption and impact absorption at elevated temperature. For instance, aircraft turbine and exhausts, supersonic aircraft structures, aerospace structures, and even advanced automobile structures often operates at high temperature and impact prone conditions.

1.2 Problem Statement

Material strength generally degrade due to rise of temperature; therefore, it is imperative to probe the extent of strength reduction on FML. Furthermore, the low-velocity impact response of FML could be significantly exacerbated at high temperature and must be investigated. What is the low-velocity impact response of FML at higher temperature? The effects of temperature towards the low-velocity impact response of FMLs are still sparse, and limited finding is only available in the general literature. Thermal stress and strains are common in aircraft structure and FML operating conditions. Metal and composite as constituents of FMLs are both temperature dependent. For instance, even when the strength of FML is good, the structure may be significantly affected by temperature.

Furthermore, impact damage causes 13% of the total repair done on the primary structure of Boeing 747 [2], and this raise concerns on the costs required ascribed to impact. There are vast possible combinations for the relatively new FML, which makes research difficult in terms of cost, time, and waste. Hence, more research is much needed to expand this field. Many studies have studied the low-velocity impact of FMLs using FE analyses, while there is currently no known investigation that includes temperature effect. The effects of temperature on the low-velocity impact response, morphology, and characteristics of FML are currently unknown.

1.3 Objective

The aim of this research is to evaluate the low-velocity impact characteristics of FML under high temperatures. The objectives are:

1. To simulate the low-velocity impact response of FML at high temperatures by utilising FE model.
2. To validate the FE models with experimental results at each temperature.
3. To perform experimental tests and implement empirical model to obtain material properties at each temperature.

4. To characterise the property degradation for FE model inputs using empirical model.
5. To examine the effects of geometrical changes on low-velocity impact at elevated temperature.

1.4 Scopes of Study

The study focuses on temperatures of 30, 70, and 110°C in experimental tests and FE validation. After validation, FE analysis on temperature effects are performed on 30, 50, 70, 90, and 110°C to scrutinise temperature effect. Temperatures below 30 and above 110°C are not covered in this research. The extent of high temperature in this study only reaches until the temperature of 110°C.

The study covers on materials including glass fibre reinforced polymer (GFRP), GFRP laminated aluminium, and glass laminated aluminium reinforced epoxy. The aluminium used is 2024-T3 grade aluminium. The GFRP is S2 grade unidirectional glass fibres prepreg with glass transition temperature (T_g) of 125°C and adhesive epoxy with T_g of 130°C. Other grades of aluminium and types of composites are not analysed. The fabrication process includes oven bonding and hand layup techniques.

The experimental tests include tensile, compression, and shear tests for properties extraction, along with double cantilever beam (DCB) and end notched flexural (ENF) tests for properties extraction and validation. Furthermore, quasi-static indentation tests and low-velocity impact tests were conducted for validation. All experimental tests are conducted in quasi-static rates of loading, except for low-velocity impact tests at impact energies of 5, 8, 10, 12, 13.5, and 15 J. Higher rates of loading and fatigue loading types are not focused on.

The numerical method consists of DCB and ENF FE models, quasi-static, and low-velocity impact models all of which simulated at temperatures of 30, 70, and 110°C. The material models used in FE modelling include Johnson-Cook material model, Chang-Chang failure criteria, and Cohesive Zone Modelling. The FE models are also modelled in half and quarter models. The parameters used for validation comprise of load-extension curves, peak loads, and slopes for DCB and ENF. Meanwhile, the validation parameters include load-displacement, damage morphology, and total energy absorption for quasi-static and low-velocity impact model.

The main study of this research includes combined analysis between impact energy of 5, 8, 10, 12, 13.5, and 15 J with temperatures 30, 50, 70, 90, and 110°C. The research also incorporates parametric studies on: first, the joint effects of impactor diameter 8, 10, 12.7, 14, and 16 mm with clamped opening diameter of 80, 100, 127, 140, and 160 mm. Secondly, the thickness ratio between aluminium and GFRP with fixed total mass of FML were investigated. Based on the validation of the FE quarter and half models, quarter model is used to simulate parametric study at 10 J based on the design limitation.

1.5 Significance of Research

Research on low-velocity impact of FMLs under high temperatures can bring much understanding, information, and improvements on the material and domain of composites. This can also ensure aeronautical and aerospace structures much safer and reliable. The methodology used in this study will provide insight on the ways of analysing performances of FMLs. The results from experimental tests provide means of creating relation or chart on temperature effect towards composite and delamination parameters for implementing them into FE models. The parametric studies on different impactor diameter, clamped opening diameter, and individual thickness of aluminium and GFRP will generate more practical and beneficial information of FMLs in different applications. Finally, the outcome of the research may facilitate the application of FML under higher temperature condition.

1.6 Thesis Chapter Summary

As presented in Chapter 1, the introduction included the background and the motivations of this study. The problem statement, main aim, objectives, and scopes of study were established. Then, the significance of this research was described.

Chapter 2 is the literature review of this research based on previous researchers. The literatures consist of the development of composite and FML structures, the scrutinization of the factors the contribute towards the composition, and the performance of FMLs. The next part involves the fabrication methods of FMLs in literature. Next, the focus turns on mechanical and thermal factors that affects FML during its operational conditions, how damage occurs, and how to evaluate them. Finally, the methods of study on FML are probed.

Chapter 3 is the methodology of this research. It consists of the material selection, material acquisition, preparation of the specimens. Specimens include GFRP, GFRP laminated aluminium, and FML. Subsequently, the experimental setup for each test are described in detail. Then, FE methodology from the model simplification, approach, and validation are outlined. The material models implemented in this study are also presented. The planning of parametric study is also covered.

Chapter 4 is the experimental results of the tensile, compression, and shear tests on GFRP, then followed by the DCB and ENF results. Furthermore, an empirical curve fitting model is implemented to study and fit the trend of each properties from the experimental results. There is also comparison with some examples from literature.

Chapter 5 detailly describes the results from quasi-static indentation tests and low-velocity impact tests on FMLs. The load-displacement curves are examined to analyse the effects of temperature and impact energy. The damage response is also compared.

Chapter 6 focuses on the detail of modelling each of the FE models, their respective validations, and results. The input of properties for the material models are described in detail. Then, delamination, quasi-static, and low-velocity impact models are presented in depth, first with the model setup, followed by the mesh convergence study. The validation of each model is shown based on the impact characteristics along with damage morphologies. Most importantly, the main results of combined effects between impact energy and temperatures are examined.

In Chapter 7, the parametric studies of geometrical properties of the FML under low-velocity impact at high temperature are presented. The first part consists of the parametric study outcome of impactor diameter and clamped opening diameter. Next, the second part involves the results from simulation different thickness ratio of aluminium and GFRP.

Lastly, Chapter 8 is the conclusion and recommendations of this research. The main research outcomes are demonstrated, followed by the major contributions towards knowledge in this field. The future works that might stem from this study are also established.

REFERENCES

[1] Chen, Y., Wang, Y., and Wang, H. Research Progress on Interlaminar Failure Behavior of Fiber Metal Laminates. Advances in Polymer Technology, 2020; 2020: p. 3097839.

[2] Vogelesang, L.B. and Vlot, A. Development of fibre metal laminates for advanced aerospace structures. Journal of Materials Processing Technology, 2000; 103(1): p. 1-5.

[3] Bieniaś, J., Jakubczak, P., and Surowska, B., *11 - Properties and characterization of fiber metal laminates*, in Hybrid Polymer Composite Materials, V.K. Thakur, M.K. Thakur, and A. Pappu, Editors. 2017, Woodhead Publishing. p. 253-277.

[4] Asundi, A. and Choi, A.Y.N. Fiber metal laminates: An advanced material for future aircraft. Journal of Materials Processing Technology, 1997; 63(1–3): p. 384-394.

[5] Roebroeks, G.H.J.J. Fibre-metal laminates: Recent developments and applications. International Journal of Fatigue, 1994; 16(1): p. 33-42.

[6] Correia, J.R., Gomes, M.M., Pires, J.M., and Branco, F.A. Mechanical behaviour of pultruded glass fibre reinforced polymer composites at elevated temperature: Experiments and model assessment. Composite Structures, 2013; 98: p. 303-313.

[7] Elanchezhian, C., Ramnath, B.V., and Hemalatha, J. Mechanical behaviour of glass and carbon fibre reinforced composites at varying strain rates and temperatures. Procedia Materials Science, 2014; 6: p. 1405-1418.

[8] Aydın, F. Effects of various temperatures on the mechanical strength of GFRP box profiles. Vol. 127. 2016. 843-849.

[9] Karakuzu, R., Erbil, E., and Aktas, M. Impact characterization of glass/epoxy composite plates: An experimental and numerical study. Composites Part B: Engineering, 2010; 41(5): p. 388-395.

[10] Sayer, M., Bektaş, N.B., and Sayman, O. An experimental investigation on the impact behavior of hybrid composite plates. Composite Structures, 2010; 92(5): p. 1256-1262.

[11] Sinmazçelik, T., Avcu, E., Bora, M.Ö., and Çoban, O. A review: Fibre metal laminates, background, bonding types and applied test methods. Materials & Design, 2011; 32(7): p. 3671-3685.

[12] Vlot, A. Impact loading on fibre metal laminates. International Journal of Impact Engineering, 1996; 18(3): p. 291-307.

[13] Vlot, A., Gunnink, J.W., and SpringerLink (Online service). Fibre metal laminates an introduction. 2001, Springer Netherlands,: Dordrecht. p. 1 online resource.

[14] Vlot, A. Impact properties of fibre metal laminates. Composites Engineering, 1993; 3(10): p. 911-927.

[15] Vlot, A., Vogelesang, L.B., and Vries, T.J.d. Towards application of fibre metal laminates in large aircraft. Aircraft Engineering and Aerospace Technology, 1999; 71(6): p. 558-570.

[16] Chai, G.B. and Manikandan, P. Low velocity impact response of fibre-metal laminates – A review. Composite Structures, 2014; 107: p. 363-381.

[17] Lawcock, G.D., Ye, L., Mai, Y.W., and Sun, C.T. Effects of fibre/matrix adhesion on carbon-fibre-reinforced metal laminates—II. impact behaviour. Composites Science and Technology, 1998; 57(12): p. 1621-1628.
[18] Li, C.F., Hu, N., Yin, Y.J., Sekine, H., and Fukunaga, H. Low-velocity impact-induced damage of continuous fiber-reinforced composite laminates. Part I. An FEM numerical model. Composites Part A: Applied Science and Manufacturing, 2002; 33(8): p. 1055-1062.
[19] Nakatani, H., Kosaka, T., Osaka, K., and Sawada, Y. Damage characterization of titanium/GFRP hybrid laminates subjected to low-velocity impact. Composites Part A: Applied Science and Manufacturing, 2011; 42(7): p. 772-781.
[20] Sadighi, M., Alderliesten, R.C., and Benedictus, R. Impact resistance of fiber-metal laminates: A review. International Journal of Impact Engineering, 2012; 49: p. 77-90.
[21] Wu, G., Yang, J.-M., and Hahn, H.T. The impact properties and damage tolerance and of bi-directionally reinforced fiber metal laminates. Journal of Materials Science, 2007; 42(3): p. 948-957.
[22] Schijve, J., Van Lipzig, H.T.M., Van Gestel, G.F.J.A., and Hoeymakers, A.H.W. Fatigue properties of adhesive-bonded laminated sheet material of aluminum alloys. Engineering Fracture Mechanics, 1979; 12(4): p. 561-579.
[23] Mitrevski, T., Marshall, I.H., and Thomson, R. The influence of impactor shape on the damage to composite laminates. Composite Structures, 2006; 76(1–2): p. 116-122.
[24] Daiyan, H., Andreassen, E., Grytten, F., Lyngstad, O.V., Luksepp, T., and Osnes, H. Low-velocity impact response of injection-moulded polypropylene plates – Part 1: Effects of plate thickness, impact velocity and temperature. Polymer Testing, 2010; 29(6): p. 648-657.
[25] Daiyan, H., Andreassen, E., Grytten, F., Lyngstad, O.V., Luksepp, T., and Osnes, H. Low-velocity impact response of injection-moulded polypropylene plates – Part 2: Effects of moulding conditions, striker geometry, clamping, surface texture, weld line and paint. Polymer Testing, 2010; 29(7): p. 894-901.
[26] Liu, Y. and Liaw, B. Effects of constituents and lay-up configuration on drop-weight tests of fiber-metal laminates. Applied Composite Materials, 2010; 17(1): p. 43-62.
[27] Abdullah, M.R. and Cantwell, W.J. The impact resistance of polypropylene-based fibre–metal laminates. Composites Science and Technology, 2006; 66(11–12): p. 1682-1693.
[28] Cortés, P. and Cantwell, W.J. The fracture properties of a fibre–metal laminate based on magnesium alloy. Composites Part B: Engineering, 2005; 37(2–3): p. 163-170.
[29] Alderliesten, R., Rans, C., and Benedictus, R. The applicability of magnesium based Fibre Metal Laminates in aerospace structures. Composites Science and Technology, 2008; 68(14): p. 2983-2993.
[30] Sadighi, M., Pärnänen, T., Alderliesten, R.C., Sayeaftabi, M., and Benedictus, R. Experimental and numerical investigation of metal type and thickness effects on the impact resistance of fiber metal laminates. Applied Composite Materials, 2012; 19(3-4): p. 545-559.
[31] Chen, Y., Chen, L., Huang, Q., and Zhang, Z. Effect of metal type on the energy absorption of fiber metal laminates under low-velocity impact. Mechanics of Advanced Materials and Structures, 2021: p. 1-17.

[32] Burianek, D.A. and Spearing, S.M. Fatigue damage in titanium-graphite hybrid laminates. Composites Science and Technology, 2002; 62(5): p. 607-617.
[33] Jakubczak, P., Bieniaś, J., and Droździel, M. The collation of impact behaviour of titanium/carbon, aluminum/carbon and conventional carbon fibres laminates. Thin-Walled Structures, 2020; 155: p. 106952.
[34] Jaroslaw, B., Barbara, S., and Patryk, J. The comparison of low-velocity impact resistance of aluminum/carbon and glass fiber metal laminates. Polymer Composites, 2016; 37(4): p. 1056-1063.
[35] Sisan, M.M. and Eslami-Farsani, R. An experimental study on impact resistance of different layup configuration of fiber metal laminates. Fibers and Polymers, 2019; 20(10): p. 2200-2206.
[36] Ferrante, L., Sarasini, F., Tirillò, J., Lampani, L., Valente, T., and Gaudenzi, P. Low velocity impact response of basalt-aluminium fibre metal laminates. Materials & Design, 2016; 98: p. 98-107.
[37] Li, X., Zhang, X., Guo, Y., Shim, V.P.W., Yang, J., and Chai, G.B. Influence of fiber type on the impact response of titanium-based fiber-metal laminates. International Journal of Impact Engineering, 2018; 114: p. 32-42.
[38] Hussain, M., Imad, A., Saouab, A., Nawab, Y., Kanit, T., Herbelot, C., and Muhammad, K. Properties and characterization of novel 3D jute reinforced natural fibre aluminium laminates. Journal of Composite Materials, 2020; 55.
[39] Subramaniam, K., Dhar Malingam, S., Feng, N.L., and Bapokutty, O. The effects of stacking configuration on the response of tensile and quasi-static penetration to woven kenaf/glass hybrid composite metal laminate. Polymer Composites, 2019; 40(2): p. 568-577.
[40] Feng, N.L., Malingam, S.D., and Ping, C.W. Mechanical characterisation of kenaf/PALF reinforced composite-metal laminates: Effects of hybridisation and weaving architectures. Journal of Reinforced Plastics and Composites; 40(5-6): p. 193-205.
[41] Badawy, A.A.M. Impact behavior of glass fibers reinforced composite laminates at different temperatures. Ain Shams Engineering Journal, 2012; 3(2): p. 105-111.
[42] Ibekwe, S.I., Mensah, P.F., Li, G., Pang, S.-S., and Stubblefield, M.A. Impact and post impact response of laminated beams at low temperatures. Composite Structures, 2007; 79(1): p. 12-17.
[43] Zhu, S. and Chai, G.B. Low-velocity impact response of fibre–metal laminates – Experimental and finite element analysis. Composites Science and Technology, 2012; 72(15): p. 1793-1802.
[44] Seyed Yaghoubi, A. and Liaw, B. Thickness influence on ballistic impact behaviors of GLARE 5 fiber-metal laminated beams: Experimental and numerical studies. Composite Structures, 2012; 94(8): p. 2585-2598.
[45] Seyed Yaghoubi, A. and Liaw, B. Effect of lay-up orientation on ballistic impact behaviors of GLARE 5 FML beams. International Journal of Impact Engineering, 2013; 54: p. 138-148.
[46] Haghi Kashani, M., Sadighi, M., Mohammadkhah, M., and Shahsavari Alavijeh, H. Investigation of scaling effects on fiber metal laminates under tensile and flexural loading. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials Design and Applications, 2013; 229(3): p. 189-201.
[47] Song, S.H., Byun, Y.S., Ku, T.W., Song, W.J., Kim, J., and Kang, B.S. Experimental and numerical investigation on impact performance of carbon

reinforced aluminum laminates. Journal of Materials Science & Technology, 2010; 26(4): p. 327-332.

[48] Tsartsaris, N., Meo, M., Dolce, F., Polimeno, U., Guida, M., and Marulo, F. Low-velocity impact behavior of fiber metal laminates. Journal of Composite Materials, 2011; 45(7): p. 803-814.

[49] Jakubczak, P., Bienias, J., and Surowska, B. The influence of fibre orientation in aluminium–carbon laminates on low-velocity impact resistance. Journal of Composite Materials, 2017; 52(8): p. 1005-1016.

[50] Asaee, Z., Shadlou, S., and Taheri, F. Low-velocity impact response of fiberglass/magnesium FMLs with a new 3D fiberglass fabric. Composite Structures, 2015; 122: p. 155-165.

[51] Asaee, Z. and Taheri, F. Enhancement of performance of three-dimensional fiber metal laminates under low velocity impact – A coupled numerical and experimental investigation. Journal of Sandwich Structures & Materials, 2019; 21(6): p. 2127-2153.

[52] De Cicco, D. and Taheri, F. Performances of magnesium- and steel-based 3D fiber-metal laminates under various loading conditions. Composite Structures, 2019; 229: p. 111390.

[53] Shanmugam, L., Kazemi, M., Qiu, C., Rui, M., Yang, L., and Yang, J. Influence of UHMWPE fiber and Ti6Al4V metal surface treatments on the low-velocity impact behavior of thermoplastic fiber metal laminates. Advanced Composites and Hybrid Materials, 2020; 3: p. 508 - 521.

[54] Hu, Y., Li, H., Tao, J., Pan, L., and Xu, J. The effects of temperature variation on mechanical behaviors of polyetheretherketone‐based fiber metal laminates. Polymer Composites, 2016.

[55] Reyes V, G. and Cantwell, W.J. The mechanical properties of fibre-metal laminates based on glass fibre reinforced polypropylene. Composites Science and Technology, 2000; 60(7): p. 1085-1094.

[56] Santiago, R., Cantwell, W., and Alves, M. Impact on thermoplastic fibre-metal laminates: Experimental observations. Composite Structures, 2017; 159: p. 800-817.

[57] Fan, J., Guan, Z.W., and Cantwell, W.J. Numerical modelling of perforation failure in fibre metal laminates subjected to low velocity impact loading. Composite Structures, 2011; 93(9): p. 2430-2436.

[58] Sharma, A.P., Khan, S.H., Kitey, R., and Parameswaran, V. Effect of through thickness metal layer distribution on the low velocity impact response of fiber metal laminates. Polymer Testing, 2018; 65: p. 301-312.

[59] Drożdziel, M., Jakubczak, P., and Bieniaś, J. Low-velocity impact resistance of thin-ply in comparison with conventional aluminium-carbon laminates. Composite Structures, 2021; 256: p. 113083.

[60] Meng, X., Yao, L., Wang, C., He, W., Xie, L., and Zhang, H. Investigation on the low-velocity impact behaviour of non-symmetric FMLs—experimental and numerical methods. International Journal of Crashworthiness, 2020: p. 1-19.

[61] Wu, H.F., Wu, L.L., Slagter, W.J., and Verolme, J.L. Use of rule of mixtures and metal volume fraction for mechanical property predictions of fibre-reinforced aluminium laminates. Journal of Materials Science, 1994; 29: p. 4583-4591.

[62] Patryk, J., Jaroslaw, B., Krzysztof, M., Monika, O., and Barbara, S. The impact behavior of aluminum hybrid laminates. Aircraft Engineering and Aerospace Technology, 2014; 86(4): p. 287-294.
[63] Thomason, J.L. The influence of fibre length, diameter and concentration on the impact performance of long glass-fibre reinforced polyamide 6,6. Composites Part A: Applied Science and Manufacturing, 2009; 40(2): p. 114-124.
[64] Vlot, A. and Van Ingen, J.W. Delamination resistance of post-stretched fibre metal laminates. Journal of Composite Materials, 1998; 32(19): p. 1784-1805.
[65] Banea, M.D., Rosioara, M., Carbas, R.J.C., and da Silva, L.F.M. Multi-material adhesive joints for automotive industry. Composites Part B: Engineering, 2018; 151: p. 71-77.
[66] Pärnänen, T., Vänttinen, A., Kanerva, M., Jokinen, J., and Saarela, O. The effects of debonding on the low-velocity impact response of steel-cfrp fibre metal laminates. Applied Composite Materials, 2016; 23(6): p. 1151-1166.
[67] Gonzalez-Canche, N.G., Flores-Johnson, E.A., and Carrillo, J.G. Mechanical characterization of fiber metal laminate based on aramid fiber reinforced polypropylene. Composite Structures, 2017; 172: p. 259-266.
[68] Hirai, Y., Hamada, H., and Kim, J.-K. Impact response of woven glass-fabric composites—I.: Effect of fibre surface treatment. Composites Science and Technology, 1998; 58(1): p. 91-104.
[69] Özşahin, E. and Tolun, S. Influence of surface coating on ballistic performance of aluminum plates subjected to high velocity impact loads. Materials & Design, 2010; 31(3): p. 1276-1283.
[70] Hu, Y.B., Li, H.G., Cai, L., Zhu, J.P., Pan, L., Xu, J., and Tao, J. Preparation and properties of Fibre–Metal Laminates based on carbon fibre reinforced PMR polyimide. Composites Part B: Engineering, 2015; 69: p. 587-591.
[71] Abdullah, M.R., Prawoto, Y., and Cantwell, W.J. Interfacial fracture of the fibre-metal laminates based on fibre reinforced thermoplastics. Materials & Design, 2015; 66, Part B: p. 446-452.
[72] Yu, G.-C., Wu, L.-Z., Ma, L., and Xiong, J. Low velocity impact of carbon fiber aluminum laminates. Composite Structures, 2015; 119: p. 757-766.
[73] Khan, S.H., Sharma, A.P., Kitey, R., and Parameswaran, V. Effect of metal layer placement on the damage and energy absorption mechanisms in aluminium/glass fibre laminates. International Journal of Impact Engineering, 2018; 119: p. 14-25.
[74] De Cicco, D., Asaee, Z., and Taheri, F. Low-velocity impact damage response of fiberglass/magnesium fiber-metal laminates under different size and shape impactors. Mechanics of Advanced Materials and Structures, 2017; 24(7): p. 545-555.
[75] Ortiz de Mendibil, I., Aretxabaleta, L., Sarrionandia, M., Mateos, M., and Aurrekoetxea, J. Impact behaviour of glass fibre-reinforced epoxy/aluminium fibre metal laminate manufactured by Vacuum Assisted Resin Transfer Moulding. Composite Structures, 2016; 140: p. 118-124.
[76] Mamalis, D., Obande, W., Koutsos, V., Blackford, J.R., Ó Brádaigh, C.M., and Ray, D. Novel thermoplastic fibre-metal laminates manufactured by vacuum resin infusion: The effect of surface treatments on interfacial bonding. Materials & Design, 2019; 162: p. 331-344.

[77] Caprino, G., Spataro, G., and Del Luongo, S. Low-velocity impact behaviour of fibreglass–aluminium laminates. Composites Part A: Applied Science and Manufacturing, 2004; 35(5): p. 605-616.
[78] Khalid, A.A. The effect of testing temperature and volume fraction on impact energy of composites. Materials & Design, 2006; 27(6): p. 499-506.
[79] Low, K.O., Teng, S.M., Johar, M., Israr, H.A., and Wong, K.J. Mode I delamination behaviour of carbon/epoxy composite at different displacement rates. Composites Part B: Engineering, 2019; 176: p. 107293.
[80] Jakubczak, P. and Bieniaś, J. Comparison of quasi static indentation and dynamic loads of glass and carbon fibre aluminium laminates. Vol. 88. 2016. 404-410.
[81] Nassir, N.A., Birch, R.S., Cantwell, W.J., Sierra, D.R., Edwardson, S.P., Dearden, G., and Guan, Z.W. Experimental and numerical characterization of titanium-based fibre metal laminates. Composite Structures, 2020; 245: p. 112398.
[82] Taghizadeh, S.A., Liaghat, G., Niknejad, A., and Pedram, E. Experimental study on quasi-static penetration process of cylindrical indenters with different nose shapes into the hybrid composite panels. Journal of Composite Materials, 2019; 53(1): p. 107-123.
[83] Haghi Kashani, M., Sadighi, M., Lalehpour, A., and Alderliesten, R. The effect of impact energy division over repeated low-velocity impact on fiber metal laminates. Journal of Composite Materials, 2014.
[84] Richardson, M.O.W. and Wisheart, M.J. Review of low-velocity impact properties of composite materials. Composites Part A: Applied Science and Manufacturing, 1996; 27(12): p. 1123-1131.
[85] Tsamasphyros, G.J. and Bikakis, G.S. Analytical modeling to predict the low velocity impact response of circular GLARE fiber–metal laminates. Aerospace Science and Technology, 2013; 29(1): p. 28-36.
[86] Bibo, G., Leicy, D., Hogg, P.J., and Kemp, M. High-temperature damage tolerance of carbon fibre-reinforced plastics. Composites, 1994; 25(6): p. 414-424.
[87] Jakubczak, P., Bieniaś, J., and Dadej, K. Experimental and numerical investigation into the impact resistance of aluminium carbon laminates. Composite Structures, 2020; 244: p. 112319.
[88] Ahmadi, H., Ekrami, M., Sabouri, H., and Bayat, M. Experimental and numerical investigation on the effect of projectile nose shape in low-velocity impact loading on fiber metal laminate panels. Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, 2019; 233(10): p. 3665-3679.
[89] Li, L., Sun, L., Wang, T., Kang, N., and Cao, W. Repeated low-velocity impact response and damage mechanism of glass fiber aluminium laminates. Aerospace Science and Technology, 2019; 84: p. 995-1010.
[90] Heydari-Meybodi, M., Mohammadkhani, H., and Bagheri, M. Oblique low-velocity impact on fiber-metal laminates. Applied Composite Materials, 2017; 24.
[91] Yao, L., Sun, G., He, W., Meng, X., and Xie, D. Investigation on impact behavior of FMLs under multiple impacts with the same total energy: Experimental characterization and numerical simulation. Composite Structures, 2019; 226: p. 111218.

[92] Morinière, F.D., Alderliesten, R.C., and Benedictus, R. Modelling of impact damage and dynamics in fibre-metal laminates – A review. International Journal of Impact Engineering, 2014; 67: p. 27-38.
[93] Hirai, Y., Hamada, H., and Kim, J.-K. Impact response of woven glass-fabric composites—II. Effect of temperature. Composites Science and Technology, 1998; 58(1): p. 119-128.
[94] Hoo Fatt, M.S., Lin, C., Revilock Jr, D.M., and Hopkins, D.A. Ballistic impact of GLARE™ fiber–metal laminates. Composite Structures, 2003; 61(1–2): p. 73-88.
[95] Daniel, I.M., Werner, B.T., and Fenner, J.S. Strain-rate-dependent failure criteria for composites. Composites Science and Technology, 2011; 71(3): p. 357-364.
[96] Shokrieh, M.M. and Omidi, M.J. Investigating the transverse behavior of Glass–Epoxy composites under intermediate strain rates. Composite Structures, 2011; 93(2): p. 690-696.
[97] Alderliesten, R.C. On the available relevant approaches for fatigue crack propagation prediction in Glare. International Journal of Fatigue, 2007; 29(2): p. 289-304.
[98] Alderliesten, R.C. Analytical prediction model for fatigue crack propagation and delamination growth in Glare. International Journal of Fatigue, 2007; 29(4): p. 628-646.
[99] Guo, Y.-J. and Wu, X.-R. A phenomenological model for predicting crack growth in fiber-reinforced metal laminates under constant-amplitude loading. Composites Science and Technology, 1999; 59(12): p. 1825-1831.
[100] Hashemi, S., Kinloch, A.J., and Williams, J.G. The effects of geometry, rate and temperature on the Mode I, Mode II and Mixed-Mode I/II interlaminar fracture of carbon-fibre/poly(ether-ether ketone) composites. Journal of Composite Materials, 1990; 24(9): p. 918-956.
[101] Johar, M., Wong, K.J., and Tamin, N. Mixed-Mode delamination failures of quasi-isotropic quasi- homogeneous carbon/epoxy laminated composite. 2017.
[102] Reis, P.N.B., Ferreira, J.A.M., Antunes, F.V., and Costa, J.D.M. Initial crack length on the interlaminar fracture of woven carbon/epoxy laminates. Fibers and Polymers, 2015; 16(4): p. 894-901.
[103] Carrillo, J.G. and Cantwell, W.J. Mechanical properties of a novel fiber–metal laminate based on a polypropylene composite. Mechanics of Materials, 2009; 41(7): p. 828-838.
[104] Hasan, M.Z. Interface failure of heated GLARE™ Fiber–Metal Laminates under bird strike. Aerospace, 2020; 7(3): p. 28.
[105] Zarei, H., Fallah, M., Minak, G., Bisadi, H., and Daneshmehr, A. Low velocity impact analysis of Fiber Metal Laminates (FMLs) in thermal environments with various boundary conditions. Composite Structures, 2016; 149: p. 170-183.
[106] Huda, Z., Zaharinie, T., and Min, G.J. Temperature effects on material behavior of aerospace aluminum alloys for subsonic and supersonic aircraft. Journal of Aerospace Engineering, 2010; 23(2).
[107] Dimitrienko, Y.I. Thermomechanical behaviour of composite materials and structures under high temperatures: 2. Structures. Composites Part A: Applied Science and Manufacturing, 1997; 28(5): p. 463-471.

[108] Zhang, L., Liu, W., Sun, G., Wang, L., and Li, L.-z. Two-dimensional modeling of thermomechanical responses of rectangular GFRP profiles exposed to fire. Vol. 2017. 2017. 1-17.
[109] Rans, C.D., Alderliesten, R.C., and Benedictus, R. Predicting the influence of temperature on fatigue crack propagation in Fibre Metal Laminates. Engineering Fracture Mechanics, 2011; 78(10): p. 2193-2201.
[110] Seidt, J.D. and Gilat, A. Plastic deformation of 2024-T351 aluminum plate over a wide range of loading conditions. International Journal of Solids and Structures, 2013; 50(10): p. 1781-1790.
[111] Bai, Y. and Keller, T. Modeling of mechanical response of FRP composites in fire. Composites Part A: Applied Science and Manufacturing, 2009; 40(6): p. 731-738.
[112] Bai, Y., Keller, T., and Vallée, T. Modeling of stiffness of FRP composites under elevated and high temperatures. Composites Science and Technology, 2008; 68(15): p. 3099-3106.
[113] Ou, Y. and Zhu, D. Tensile behavior of glass fiber reinforced composite at different strain rates and temperatures. Construction and Building Materials, 2015; 96: p. 648-656.
[114] Kumar, M.K., Krishna, D., and Chandra, R.B. High‐temperature tensile behavior at different crosshead speeds during loading of glass fiber‐reinforced polymer composites. Journal of Applied Polymer Science, 2017; 134(16).
[115] Gabrion, X., Placet, V., Trivaudey, F., and Boubakar, L. About the thermomechanical behaviour of a carbon fibre reinforced high-temperature thermoplastic composite. Composites Part B: Engineering, 2016; 95: p. 386-394.
[116] Hawileh, R.A., Abu-Obeidah, A., Abdalla, J.A., and Al-Tamimi, A. Temperature effect on the mechanical properties of carbon, glass and carbon–glass FRP laminates. Construction and Building Materials, 2015; 75: p. 342-348.
[117] Jarrah, M., Najafabadi, E.P., Khaneghahi, M.H., and Oskouei, A.V. The effect of elevated temperatures on the tensile performance of GFRP and CFRP sheets. Construction and Building Materials, 2018; 190: p. 38-52.
[118] Lu, Z., Xian, G., and Li, H. Effects of elevated temperatures on the mechanical properties of basalt fibers and BFRP plates. Construction and Building Materials, 2016; 127: p. 1029-1036.
[119] Rosa, I., Morgado, T., Correia, J., Firmo, J., and Silvestre, N. Shear behavior of GFRP composite materials at elevated temperature. Vol. 22. 2018. 04018010.
[120] Wang, L., Fan, X., Chen, H., and Liu, W. Axial crush behavior and energy absorption capability of foam-filled GFRP tubes under elevated and high temperatures. Composite Structures, 2016; 149: p. 339-350.
[121] Aklilu, G., Adali, S., and Bright, G. Temperature effect on mechanical properties of carbon, glass and hybrid polymer composite specimens. Vol. 39. 2018. 119-138.
[122] Bazli, M., Ashrafi, H., Jafari, A., Zhao, X.-L., Gholipour, H., and Oskouei, A.V. Effect of thickness and reinforcement configuration on flexural and impact behaviour of GFRP laminates after exposure to elevated temperatures. Composites Part B: Engineering, 2019; 157: p. 76-99.

[123] Houshmand, M., Jarrah, M., and Pournamazian Najafabadi, E. The effect of elevated temperatures on the tensile performance of GFRP and CFRP sheets. Vol. 190. 2018. 38-52.
[124] Gibson, A.G., Wu, Y.S., Evans, J.T., and Mouritz, A.P. Laminate theory analysis of composites under load in fire. Journal of Composite Materials, 2005; 40(7): p. 639-658.
[125] Mahieux, C.A., Reifsnider, K.L., and Case, S.W. Property modeling across transition temperatures in PMC's: Part i. Tensile properties. Applied Composite Materials, 2001; 8(4): p. 217-234.
[126] Sengodan, G.A., Allegri, G., and Hallett, S.R. Simulation of progressive failure in laminated composites under variable environmental conditions. Materials & Design, 2020; 196: p. 109082.
[127] Ramírez, F.M.G., Garpelli, F.P., Sales, R.d.C.M., Cândido, G.M., Arbelo, M.A., Shiino, M.Y., and Donadon, M.V. Hygrothermal effects on the fatigue delamination growth onset in interlayer toughened CFRP joints. International Journal of Fatigue, 2020; 138: p. 105729.
[128] Tsokanas, P. and Loutas, T. Hygrothermal effect on the strain energy release rates and mode mixity of asymmetric delaminations in generally layered beams. Engineering Fracture Mechanics, 2019; 214: p. 390-409.
[129] Tsokanas, P., Loutas, T., Kotsinis, G., Kostopoulos, V., van den Brink, W.M., and Martin de la Escalera, F. On the fracture toughness of metal-composite adhesive joints with bending-extension coupling and residual thermal stresses effect. Composites Part B: Engineering, 2020; 185: p. 107694.
[130] Czabaj, M.W. and Davidson, B.D. Determination of the mode I, mode II, and mixed-mode I–II delamination toughness of a graphite/polyimide composite at room and elevated temperatures. Journal of Composite Materials, 2015; 50(16): p. 2235-2253.
[131] Charalambous, G., Allegri, G., and Hallett, S.R. Temperature effects on mixed mode I/II delamination under quasi-static and fatigue loading of a carbon/epoxy composite. Composites Part A: Applied Science and Manufacturing, 2015; 77: p. 75-86.
[132] Argüelles, A., Viña, J., Canteli, A.F., Coronado, P., and Mollón, V. Influence of temperature on the delamination process under mode I fracture and dynamic loading of two carbon–epoxy composites. Composites Part B: Engineering, 2015; 68: p. 207-214.
[133] Cadieu, L., Kopp, J.B., Jumel, J., Bega, J., and Froustey, C. A fracture behaviour evaluation of Glass/Elium150 thermoplastic laminate with the DCB test: Influence of loading rate and temperature. Composite Structures, 2021; 255: p. 112907.
[134] Davidson, B.D., Kumar, M., and Soffa, M.A. Influence of mode ratio and hygrothermal condition on the delamination toughness of a thermoplastic particulate interlayered carbon/epoxy composite. Composites Part A: Applied Science and Manufacturing, 2009; 40(1): p. 67-79.
[135] Wu, H.F. Effect of temperature and strain rate on tensile mechanical properties of ARALL-1 laminates. Journal of Materials Science, 1991; 26(14): p. 3721-3729.
[136] Wu, H.F. Temperature dependence of the tensile behaviour of aramid/aluminium laminates. Journal of Materials Science, 1993; 28(1): p. 19-34.

[137] Sarasini, F., Tirillò, J., Ferrante, L., Sergi, C., Sbardella, F., Russo, P., Simeoli, G., Mellier, D., and Calzolari, A. Effect of temperature and fiber type on impact behavior of thermoplastic fiber metal laminates. Composite Structures, 2019; 223: p. 110961.
[138] Cortés, P. and Cantwell, W.J. The impact properties of high-temperature fiber-metal laminates. Journal of Composite Materials, 2006; 41(5): p. 613-632.
[139] da Costa, A.A., da Silva, D., Travessa, D.N., and Botelho, E.C. The effect of thermal cycles on the mechanical properties of fiber-metal laminates. Materials & Design, 2012; 42: p. 434-440.
[140] Li, H., Hu, Y., Liu, C., Zheng, X., Liu, H., and Tao, J. The effect of thermal fatigue on the mechanical properties of the novel fiber metal laminates based on aluminum–lithium alloy. Composites Part A: Applied Science and Manufacturing, 2016; 84: p. 36-42.
[141] Müller, B., Hagenbeek, M., and Sinke, J. Thermal cycling of (heated) fibre metal laminates. Composite Structures, 2016; 152: p. 106-116.
[142] López-Puente, J., Zaera, R., and Navarro, C. The effect of low temperatures on the intermediate and high velocity impact response of CFRPs. Composites Part B: Engineering, 2002; 33(8): p. 559-566.
[143] Morinière, F.D., Alderliesten, R.C., and Benedictus, R. Low-velocity impact energy partition in GLARE. Mechanics of Materials, 2013; 66: p. 59-68.
[144] Yao, L., Wang, C., He, W., Lu, S., and Xie, D. Influence of impactor shape on low-velocity impact behavior of fiber metal laminates combined numerical and experimental approaches. Thin-Walled Structures, 2019; 145: p. 106399.
[145] Cantwell, W.J. and Morton, J. Impact perforation of carbon fibre reinforced plastic. Composites Science and Technology, 1990; 38(2): p. 119-141.
[146] Seo, H., Hundley, J., Hahn, H.T., and Yang, J.-M. Numerical simulation of glass-fiber-reinforced aluminum laminates with diverse impact damage. AIAA Journal, 2010; 48(3): p. 676-687.
[147] Iannucci, L. Progressive failure modelling of woven carbon composite under impact. International Journal of Impact Engineering, 2006; 32(6): p. 1013-1043.
[148] Azhdari, S., Fakhreddini-Najafabadi, S., and Taheri-Behrooz, F. An experimental and numerical investigation on low velocity impact response of GLAREs. Composite Structures, 2021; 271: p. 114123.
[149] Wang, P., Yang, J., Liu, M., Zhang, X., Sun, D., Bao, C., Gao, G., Yahya, Y., and Songlin, x. Modification of the contact surfaces for improving the puncture resistance of laminar structures. Scientific Reports, 2017; 7.
[150] Payeganeh, G.H., Ashenai Ghasemi, F., and Malekzadeh, K. Dynamic response of fiber–metal laminates (FMLs) subjected to low-velocity impact. Thin-Walled Structures, 2010; 48(1): p. 62-70.
[151] Abrate, S. Modeling of impacts on composite structures. Composite Structures, 2001; 51(2): p. 129-138.
[152] Langdon, G.S., Lemanski, S.L., Nurick, G.N., Simmons, M.C., Cantwell, W.J., and Schleyer, G.K. Behaviour of fibre–metal laminates subjected to localised blast loading: Part I—Experimental observations. International Journal of Impact Engineering, 2007; 34(7): p. 1202-1222.
[153] Lemanski, S.L., Nurick, G.N., Langdon, G.S., Simmons, M.C., Cantwell, W.J., and Schleyer, G.K. Behaviour of fibre metal laminates subjected to localised blast loading—Part II: Quantitative analysis. International Journal of Impact Engineering, 2007; 34(7): p. 1223-1245.

[154] Morinière, F.D., Alderliesten, R.C., Sadighi, M., and Benedictus, R. An integrated study on the low-velocity impact response of the GLARE fibre-metal laminate. Composite Structures, 2013; 100: p. 89-103.
[155] Ibrahim, G.R. and Albarbar, A. A new approach to the cohesive zone model that includes thermal effects. Composites Part B: Engineering, 2019; 167: p. 370-376.
[156] Günther, N., Griese, M., Stammen, E., and Dilger, K. Modeling of adhesive layers with temperature-dependent cohesive zone elements for predicting adhesive failure during the drying process of cathodic dip painting. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 2019; 233(3): p. 485-494.
[157] Bikakis, G.S.E. and Savaidis, A. FEM simulation of simply supported GLARE plates under lateral indentation loading and unloading. Theoretical and Applied Fracture Mechanics, 2016; 83: p. 2-10.
[158] Bikakis, G.S. Response of circular GLARE fiber–metal laminates subjected to oblique indentation. Journal of Reinforced Plastics and Composites, 2016; 35(18): p. 1329-1341.
[159] Bikakis, G.S. Finite element and analytical modeling to predict the frictional oblique indentation response of GLARE fiber–metal laminates. Journal of Reinforced Plastics and Composites, 2017; 36(11): p. 797-807.
[160] Bienias, J., Jakubczak, P., and Dadej, K. Low-velocity impact resistance of aluminium glass laminates – Experimental and numerical investigation. Composite Structures, 2016; 152: p. 339-348.
[161] Frizzell, R.M., McCarthy, C.T., and McCarthy, M.A. Simulating damage and delamination in fibre metal laminate joints using a three-dimensional damage model with cohesive elements and damage regularisation. Composites Science and Technology, 2011; 71(9): p. 1225-1235.
[162] Karagiozova, D., Langdon, G.S., Nurick, G.N., and Chung Kim Yuen, S. Simulation of the response of fibre–metal laminates to localised blast loading. International Journal of Impact Engineering, 2010; 37(6): p. 766-782.
[163] Hashagen, F. and de Borst, R. Numerical assessment of delamination in fibre metal laminates. Computer Methods in Applied Mechanics and Engineering, 2000; 185(2–4): p. 141-159.
[164] Johnson, G.R. and Cook, W.H. Fracture characteristics of three metals subjected to various strains, strain rates, temperatures and pressures. Engineering Fracture Mechanics, 1985; 21(1): p. 31-48.
[165] Matzenmiller, A., Lubliner, J., and Taylor, R.L. A constitutive model for anisotropic damage in fiber-composites. Mechanics of Materials, 1995; 20(2): p. 125-152.
[166] Barbieri, E. and Meo, M. A meshfree penalty-based approach to delamination in composites. Composites Science and Technology, 2009; 69(13): p. 2169-2177.
[167] Pascoe, J.A., Alderliesten, R.C., and Benedictus, R. Methods for the prediction of fatigue delamination growth in composites and adhesive bonds – A critical review. Engineering Fracture Mechanics, 2013; 112–113: p. 72-96.
[168] Turon, A., Dávila, C.G., Camanho, P.P., and Costa, J. An engineering solution for mesh size effects in the simulation of delamination using cohesive zone models. Engineering Fracture Mechanics, 2007; 74(10): p. 1665-1682.
[169] Turon, A., Camanho, P.P., Costa, J., and Renart, J. Accurate simulation of delamination growth under mixed-mode loading using cohesive elements:

Definition of interlaminar strengths and elastic stiffness. Composite Structures, 2010; 92(8): p. 1857-1864.
[170] LeBlanc, L.R. and LaPlante, G. Experimental investigation and finite element modeling of mixed-mode delamination in a moisture-exposed carbon/epoxy composite. Composites Part A: Applied Science and Manufacturing, 2016; 81: p. 202-213.
[171] Johar, M., Israr, H.A., Low, K.O., and Wong, K.J. Numerical simulation methodology for mode II delamination of quasi-isotropic quasi-homogeneous composite laminates. Journal of Composite Materials, 2017; 51(28): p. 3955-3968.
[172] R. Koloor, S.S. and Tamin, M.N. Mode-II interlaminar fracture and crack-jump phenomenon in CFRP composite laminate materials. Composite Structures, 2018; 204: p. 594-606.
[173] Liao, B.B. and Liu, P.F. Finite element analysis of dynamic progressive failure properties of GLARE hybrid laminates under low-velocity impact. Journal of Composite Materials, 2017; 52(10): p. 1317-1330.
[174] Li, H., Xu, Y., Hua, X., Liu, C., and Tao, J. Bending failure mechanism and flexural properties of GLARE laminates with different stacking sequences. Composite Structures, 2018; 187: p. 354-363.
[175] Manikandan, P. and Chai, G.B. Mode-I metal-composite interface fracture testing for fibre metal laminates. Advances in Materials Science and Engineering, 2018; 2018: p. 11.
[176] Zhao, L., Gong, Y., Zhang, J., Chen, Y., and Fei, B. Simulation of delamination growth in multidirectional laminates under mode I and mixed mode I/II loadings using cohesive elements. Composite Structures, 2014; 116: p. 509-522.
[177] Delbariani-Nejad, A., Malakouti, M., and Farrokhabadi, A. Reliability analysis of metal‐composite adhesive joints under debonding modes I, II, and I/II using the results of experimental and FEM analyses. Fatigue & Fracture of Engineering Materials & Structures, 2019; 42: p. 2644-2662.
[178] Qin, G., Na, J., Tan, W., Mu, W., and Ji, J. Failure prediction of adhesively bonded CFRP-Aluminum alloy joints using cohesive zone model with consideration of temperature effect. The Journal of Adhesion, 2019; 95(8): p. 723-746.
[179] Sun, X.C. and Hallett, S.R. Barely visible impact damage in scaled composite laminates: Experiments and numerical simulations. International Journal of Impact Engineering, 2017; 109: p. 178-195.
[180] Shi, Y., Pinna, C., and Soutis, C. Impact damage characteristics of carbon fibre metal laminates: Experiments and simulation. Applied Composite Materials, 2020; 27(5): p. 511-531.
[181] Shi, Y., Pinna, C., and Soutis, C. Modelling impact damage in composite laminates: A simulation of intra- and inter-laminar cracking. Composite Structures, 2014; 114: p. 10-19.
[182] Lesuer, D. Experimental investigations of material models for TI-6A1-4V titanium and 2024-t3 aluminum. 2000, Lawrence Livermore National Lab.: United States.
[183] ASTM D3039 / D3039M-14, Standard test method for tensile properties of polymer matrix composite materials. ASTM International, West Conshohocken, PA, 2014.

[184] ASTM D6641 / D6641M-14, Standard test method for compressive properties of polymer matrix composite materials using a combined loading compression (CLC) test fixture. ASTM International, West Conshohocken, PA, 2014.
[185] ASTM D3518 / D3518M-13, Standard test method for in-plane shear response of polymer matrix composite materials by tensile test of a ±45° laminate. ASTM International, West Conshohocken, PA, 2013.
[186] ASTM D5528-13, Standard test method for mode i interlaminar fracture toughness of unidirectional fiber-reinforced polymer matrix composites. ASTM International, West Conshohocken, PA, 2013.
[187] ASTM D7905 / D7905M-14, Standard test method for determination of the Mode II interlaminar fracture toughness of unidirectional fiber-reinforced polymer matrix composites. ASTM International, West Conshohocken, PA, 2014.
[188] Chow, Z.P., Ahmad, Z., Wong, K.J., and Israr, H.A. Thermo-mechanical characterisation and modelling of GFRP laminated aluminium. Composites Part B: Engineering, 2019; 173: p. 106971.
[189] Chang, F.-K. and Chang, K.-Y. A progressive damage model for laminated composites containing stress concentrations. Journal of Composite Materials, 1987; 21(9): p. 834-855.
[190] Gerlach, S., Fiolka, M., and Matzenmiller, A. Modelling and analysis of adhesively bonded joints with interface elements for crash analysis. 2005.
[191] Wong, K.J., Israr, H.A., and Tamin, M.N. Characterisation of moisture absorption effects on the strength of composite materials. Advanced Materials Research, 2015; 1125: p. 69-73.
[192] Opelt, C., Faulstich de Paiva, J., Cândido, G.M., and Rezende, M.C. A fractographic study on the effects of hygrothermal conditioning on carbon fiber/epoxy laminates submitted to axial compression. Vol. 79. 2017.
[193] Gong, Y., Zhao, L., Zhang, J., Wang, Y., and Hu, N. Delamination propagation criterion including the effect of fiber bridging for mixed-mode I/II delamination in CFRP multidirectional laminates. Composites Science and Technology, 2017; 151: p. 302-309.
[194] Bosbach, B., Ohle, C., and Fiedler, B. Structural health monitoring of fibre metal laminates under mode I and II loading. Composites Part A: Applied Science and Manufacturing, 2018; 107: p. 471-478.
[195] De Baere, I., Jacques, S., Van Paepegem, W., and Degrieck, J. Study of the Mode I and Mode II interlaminar behaviour of a carbon fabric reinforced thermoplastic. Polymer Testing, 2012; 31(2): p. 322-332.
[196] Ou, Y., Zhu, D., Zhang, H., Huang, L., Yao, Y., li, G., and Mobasher, B. Mechanical characterization of the tensile properties of glass fiber and its reinforced polymer (GFRP) composite under varying strain rates and temperatures. Vol. 8. 2016. 196.
[197] Wong, K.J. Moisture absorption characteristics and effects on mechanical behaviour of carbon/epoxy composite : application to bonded patch repairs of composite structures. 2013, Université de Bourgogne.
[198] Vlot, A.D., Kroon, E., and La Rocca, G. Impact response of fiber metal laminates. Key Engineering Materials - KEY ENG MAT, 1998; 141-143: p. 235-276.
[199] Jakubczak, P. The impact behaviour of hybrid titanium glass laminates—Experimental and numerical approach. International Journal of Mechanical Sciences, 2019; 159: p. 58-73.

[200] Wen, Q., li, W., Wang, W.B., Wang, F., Gao, Y.J., and Patel, V. Experimental and numerical investigations of bonding interface behavior in stationary shoulder friction stir lap welding. Journal of Materials Science & Technology, 2018; 35(1): p. 192-200.

[201] Wong, K.J., Johar, M., Rahimian Koloor, S.S., Petru, M., and Tamin, M. Moisture absorption effects on Mode II delamination of carbon/epoxy composites. Polymers, 2020; 12: p. 1-13.

[202] Pan, Y., Wu, G., Cheng, X., Zhang, Z., Li, M., Ji, S., and Huang, Z. Mode I and Mode II interlaminar fracture toughness of CFRP/magnesium alloys hybrid laminates. Composite Interfaces, 2016; 23(5): p. 453-465.

[203] Yelamanchi, B., MacDonald, E., Gonzalez-Canche, N.G., Carrillo, J.G., and Cortes, P. The mechanical properties of fiber metal laminates based on 3D printed composites. Materials, 2020; 13(22): p. 5264.

LIST OF PUBLICATIONS

Journal with Impact Factor

1. **Chow, Z.P.**, Ahmad, Z., Wong, K.J., and Israr, H.A. Thermo-mechanical characterisation and modelling of GFRP laminated aluminium. Composites Part B: Engineering, 2019; 173: p. 106971. https://doi.org/10.1016/j.compositesb.2019.106971. **(Q1 ISI Indexed IF = 9.078)**

2. **Chow, Z.P.**, Ahmad, Z., Wong, K.J., Koloor, S.S.R., and Petrů, M. Thermal Delamination Modelling and Evaluation of Aluminium-Glass Fibre-Reinforced Polymer Hybrid. Polymers (Basel), 2021; 13(4): p. 492. https://doi.org/10.3390/polym13040492. **(Q1 ISI Indexed IF = 4.329)**

3. **Chow, Z.P.**, Ahmad, Z., Wong, K.J., and Syed Abdullah, S.I. Experimental and Numerical Analyses of Temperature Effect on Glare Panels under Quasi-Static Perforation. Composite Structures, 2021; 275: p. 114434. https://doi.org/10.1016/j.compstruct.2021.114434. **(Q2 ISI Indexed IF = 5.407)**

4. **Chow, Z.P.**, Ahmad, Z., and Wong, K.J. Temperature Effects on the Low-Velocity Impact of FML Panels: Experimental and Numerical Analyses. International Journal of Impact Engineering [Under Review], 2021. **(Q1 ISI Indexed IF = 4.208)**

Indexed Journal

1. **Chow, Z.P.**, Ahmad, Z., and Wong, K.J. Experimental Study on the Mechanical Properties of Glass Fiber Reinforced Epoxy at Elevated Temperature. International Journal of Automotive and Mechanical Engineering, 2019; 16(3): p. 7108-7120.

https://doi.org/10.15282/ijame.16.3.2019.19.0531. **(Scopus Indexed SJR = 0.311)**

Indexed Book Series

1. **Chow, Z.P.**, Ahmad, Z., and Wong, K.J. Experimental Study of Temperature Effect on the Mechanical Properties of GFRP and FML Interface. Advanced Structured Materials, 2020; 113: p. 47-58. https://doi.org/10.1007/978-3-030-20801-1_4. **(Scopus Indexed SJR = 0.168)**

Non-Indexed Journal

1. **Chow, Z.P.**, Ahmad, Z., and Wong, K.J. Temperature Effect Evaluation of FML Panels under Quasi Static Indentation Loading. Science International (Lahore), 2019; 31(2): p. 291-295.

Indexed Conference Proceedings

1. Sofi, M., **Chow, Z.**, Wong, K.J., and Ahmad, Z. Study of multi-cell thin-walled tube with various configuration under lateral loading. IOP Conference Series: Materials Science and Engineering, 2020; 884: p. 012086. https://doi.org/10.1088/1757-899X/884/1/012086. **(Scopus Indexed SJR = 0.198)**