SIMULATION METHODOLOGY FOR FRACTURE PROCESSES OF COMPOSITE LAMINATES USING DAMAGE-BASED MODELS

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To my beloved
Prof. Mohd Nasir, Dad and Mom, my wonderful wife Atefeh, my brother Mustafa,
and my sisters Maryam and Masoomeh.

To my friends for their endless love and supports…

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ABSTRACT

Fiber-reinforced polymer composite (FRP) laminates have found increasing use in advanced industrial applications. However, the limited knowledge and validated material models of the failure processes of the laminated composites continue to pose challenges in ensuring reliability and integrity of the structures. This research aims at establishing a validated simulation methodology for fracture assessment of FRP composite laminates. The approach accounts for the failure processes and the associated damage mechanisms through finite element (FE) simulations. The FE model development considers the existence of the physical interfaces between the laminas due to the manufacturing processes. A hybrid experimental-computational approach is developed for systematic implementation of the simulation methodology. Different combinations of the failure modes were observed, including matrix cracking-crushing, fiber/matrix interface debonding, interface multi-delamination, and fiber fracture-buckling. Local material failure is modeled by a damage initiation event followed by the evolution of the damage to fracture. Two types of damage-based models are investigated; the continuum damage model encompassing the multi-damage criteria for the FRP composite lamina and the cohesive zone model for interface delamination. A full derivation of the continuum damage model for the anisotropic material is given and employed for prediction of the damage evolution in the lamina. A series of experiments on CFRP and GFRP composite laminate specimens are conducted to establish the flexural and fracture behaviors of the materials. Complementary 3D FE models of the specimens and test setups are developed. Two different FE-based models, namely the *conventional* and *Prepreg* model, are developed and examined for GFRP and CFRP composites. Results show that accurate prediction of elastic-damage behavior and the progressive damage process in FRP composites depend on the chosen FE-based model of the FRP composite laminates and the damage-based material model used. The flexural test of a 12-ply antisymmetric CFRP composite beam specimen under four-point bending displayed the occurrence of multiple failure events. These include matrix cracking at lamina No. 9 (90^o), and delamination at interfaces No. 8 ($-45^o/90^o$) and No. 9 ($90^o/45^o$). In addition, intralaminar multi-failure events are predicted in lamina No. 1 (-45^o) due to matrix shear and fiber buckling failures. FE simulation of the test predicted an accurate flexural response with less than 4% average error when compared with measured data, along with similar multiple failure zones in the specimen. Damage dissipation energy is used to illustrate the quantity of the overall progressive damage in FRP laminas, interfaces and the laminated composite. The simultaneous use of lamina and interface damage models in the FE simulation of the FRP composite laminate is recommended in view of the occurrence of multiple intralaminar-interlaminar failure modes and fractures under general loading conditions.

ABSTRAK

Penggunaan laminat komposit polimer bertetulang gentian (FRP) dalam industri termaju didapati telah meningkat. Walau bagaimanapun, pengetahuan yang terhad dan model bahan tervalidasi untuk proses kegagalan laminat komposit tersebut terus memberi cabaran dalam memastikan kebolehharapan dan integriti sesuatu struktur. Kajian ini bertujuan untuk menghasilkan suatu metodologi simulasi tervalidasi bagi penilaian patah laminat komposit FRP. Pendekatan ini mengambil kira proses kegagalan dan mekanisme kerosakan yang berkaitan melalui simulasi unsur terhingga (FE). Pembangunan model FE mengambil kira kewujudan lapisan fizikal di antara lamina-lamina yang terhasil dari proses pembuatan. Suatu pendekatan eksperimen-komputeraan hibrid dibangunkan untuk pelaksanaan metodologi simulasi yang sistematik. Gabungan mod kegagalan yang berbeza telah diperhatikan termasuk retak-hancur matrik, lekangan gentian/matrik, berbilang lekangan antara-muka dan ledingann-patah gentian. Kegagalan setempat bahan dimodel oleh kejadian kerosakan permulaan dan diikuti oleh evolusi kerosakan sehingga patah. Dua jenis model berasaskan kerosakan telah disiasat; model kerosakan kontinum yang merangkumi kriteria pelbagai kerosakan untuk lamina komposit FRP dan model zon kohesif untuk lekangan antara-muka. Suatu terbitan penuh model kerosakan kontinum untuk bahan anisotropik telah disediakan dan diguna pakai untuk ramalan evolusi kerosakan dalam lamina. Suatu siri eksperimen ke atas spesimen laminat komposit CFRP dan GFRP telah dijalankan untuk mewujudkan gaya laku lenturan dan patah bahan. Model pelengkap FE 3D untuk spesimen dan tentuatur ujian telah dibangunkan. Dua model FE yang berbeza; iaitu model *conventional* dan *prepreg* telah dibangunkan dan diteliti untuk komposit GFRP dan CFRP. Keputusannya menunjukkan bahawa ramalan tepat kelakuan anjal-rosak dan proses kerosakan yang progresif dalam komposit FRP bergantung kepada model FE yang dipilih untuk laminat komposit FRP tersebut dan model berasaskan kerosakan yang diguna pakai. Ujian lenturan ke atas specimen rasuk komposit CFRP 12-lapis yang antisimetri di bawah beban titik-empat lenturan menunjukkan berlakunya kejadian pelbagai kegagalan. Ini termasuk keretakan matrik pada lamina No. 9 (90^o), dan lekangan pada antara-muka No. 8 ($-45^o/90^o$) dan No. 9 ($90^o/45^o$). Tambahan lagi, kejadian pelbagai kegagalan dalam-lamina diramal berlaku dalam lamina No.1 (-45^o) disebabkan oleh ricih matrik dan kegagalan ledingan gentian. Simulasi FE ujian tersebut meramalkan respon lenturan yang tepat dengan ralat purata kurang daripada 4% berbanding dengan data yang diukur, berserta zon kegagalan yang serupa di dalam specimen. Tenaga pelesapan rosak boleh digunakan untuk menggambarkan kuantiti keseluruhan proses kerosakan yang progresif dalam lamina-lamina FRP, antara-muka dan laminat komposit. Penggunaan serentak model kerosakan lamina dan antara-muka dalam simulasi FE bagi laminat komposit FRP adalah disyorkan memandangkan boleh berlakunya pelbagai mod kegagalan dalam-lamina/antara-lamina dan keretakan di bawah keadaan pembebanan umum.

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LIST OF ABBREVIATIONS

AFR	-	Automated fiber replacement
ASTM	-	American society of testing method
ATL	-	Automated tape laying
CDM	-	Continuum damage model
CFRP	-	Carbon fiber reinforced polymer
CNC	-	Carbon nanocoil
CNF	-	Carbon nanofiber
CNT	-	Carbon nanotubes
CVD	-	Chemical vapor decomposition
CZM	-	Cohesive zone model
DCB	-	Double cantilever beam
DI	-	Damage initiation
DP	-	Damage propagation
DPL	-	Deviation point from linearity
ELS	-	End loaded split
ENF	-	End-notched flexure
FE	-	Finite element
FEM	-	Finite element method
FLF	-	First lamina failure
FRP	-	Fiber-reinforced polymer
GFRP	-	Glass fiber reinforced polymer
GLARE	-	Glass laminate aluminum reinforced epoxy
HME	-	Hypothesis of mechanical equivalence
HSE	-	Hypothesis of strain equivalence
LEFM	-	Linear elastic fracture mechanics
LSL	-	Linear softening law

MBT	-	Modifed beam theory
ML	-	Maximum load
PR	-	Poisson's ratio effect
RFI	-	Resin film infusion
RTM	-	Resin transfer molding
SLSSZ	-	Stable limit of shear stretch zone
SEM	-	Scanning electron microscope
microCT	-	micro computer tomography
VAP	-	Vacuum-assisted Resin process
VIP	-	Vacuum infusion process
WWFE	-	worldwide failure exercises
3D	-	Three-dimensional

LIST OF SYMBOLS

E - Young's modulus
ν - Poisson's ratio
$\overline{Q}_{ij}$ - Element of the transformed reduced stiffness matrix
Z - Distance from the central line
ε^{o} - Strain at $Z = 0$ (center-line of the composite beam)
E_{o} - Original material stiffness
$E_{(D)}$ - Elastic modulus of the material at damaged state
D - Scalar damage variable
σ - Nominal, true or Cauchy stress tensor
$\hat{\sigma}_{ij}$ - Effective stress component
$E_{(D)}$ - Elastic modulus of the structure at damaged state
Y_{C} - Normal strength perpendicular to fiber direction under compression loading condition
S_{12} - Shear strength
α - Shear direction
Y_{T} - Normal strength perpendicular to fiber direction under tension loading condition
σ_{22}^{m} - Normal stress in 2D kinking frame
τ_{12}^{m} - Shear stress in 2D kinking frame
$\overline{\sigma}$ - Effective normal stress
$\overline{\tau}$ - Effective shear stress
φ - Matrix crack density
ζ - Curve fitting parameter
Z_{T} - Traction strength along through-thickness of interface
K - Curve fitting parameter

k - Number of nodes in a lamina

f - Number of nodes in one surface of a lamina

h - Number of elements through a lamina thickness

n - Number of the laminas

$\mathrm{K}_{\mathrm{Conv}}$ - Number of nodes in lcomposite aminate with conventional model

$\mathrm{K}_{\mathrm{Prep}}$ - Number of nodes in composite laminate with prepreg model

$\varepsilon_{\mathrm{ij}}$ - Normal strain compoinent of strain tensor

γ_{ij} - Shear strain compoinent of strain tensor

σ_{ij} - Normal stress compoinent of stress tensor

τ_{ij} - Shear stress compoinent of stress tensor

$\varepsilon_{\mathrm{i}}^{0}$ - Midplane normal strain of composite laminate

γ_{ij}^{0} - Midplane shear strain of composite laminate

K_{i} - Midplane curvature of composite laminate

$\mathrm{f}_{(\sigma_{\mathrm{ij}})}$ - Function of stress tensor component

Υ - Yield stress of a bar under uniaxial tension load

$\mathrm{d}_{11}^{\mathrm{t}}$ - Internal damage variable of lamina in fiber direction under tension load

$\mathrm{d}_{11}^{\mathrm{c}}$ - Internal damage variable of lamina in fiber direction undercompression load

$\mathrm{d}_{22}^{\mathrm{t}}$ - Internal damage variable of lamina perpendicular to fiber direction under tension load

$\mathrm{d}_{22}^{\mathrm{c}}$ - Internal damage variable of lamina perpendicular to fiber direction under compression load

X^{T} - Lamina normal strength in fiber direction under tension load

Y^{T} - Lamina normal strength perpendicular to fiber direction under tension load

X^{C} - Lamina normal strength in fiber direction under compression load

Y^{C} - Lamina normal strength perpendicular to fiber direction under compression load

S^{L} - Lamina longitudinal shear strength

S^T - Lamina transverse shear strength

G_{XT} - Longitudinal tensile fracture energy

G_{XC} - Longitudinal compressive fracture energy

G_{YT} - Transverse tensile fracture energy

G_{YC} - Transverse compressive fracture energy

M - Damage effect tensor

$k_{eq.}^{0}$ - Orginal equivalent stiffness prior to damage initiation

$\delta_{eq.}^{o}$ - Equivalent displacement at damage initiation

δ_{eq}^{f} - Equivalent displacement at failure

σ_{eq} - Equivalent stress of failure modes

σ_{eq}^{f} - Equivalent stress at failure

C_o - Elastic compliance tensor

D_P - Damage propagation parameter

G - Strain energy release rate

L^c - Characteristic length in the reference surface of shell elements

G_C - Critical energy release rate

G_T - Total energy release rate

G_{DDE} - Damage dissipation energy

F_i - Force in i^{th} node

u_j - Motion of the node j^{th}

T_i - Composnent of traction

δ_{Shear} - Equivalent relative shear displacement

β - Mode mixity in interface material point

G_{Shear} - Energy release rate of mixed shear loading in modes II and III

G_I - Energy release rate in mode I

G_{II} - Energy release rate in mode II

G_{III} - Energy release rate in mode III

G_{IC} - Critical energy release rate in mode I

G_{IIC} - Critical Energy release rate in mode II

G_{IIIC} - Critical Energy release rate in mode III

G_{TC} - Total critical strain energy release rate in mixed-mode loading condition

$\delta_{i_m}^{f}$ - Relative displacement at failure under mixed-mode loading for each mode of interface damage

D_{sr} - Operator of the interface constitutive model

$\bar{\delta}_{sr}$ - Kronecker delta

P - Current mass density

υ - Velocity field vector

U - Internal energy per unit mass

t - Surface traction vector

$\mathbf{f}$ - Body force vector

$\mathrm{E_U}$ - Dissipated portions of the internal energy

$\mathrm{E_K}$ - Kinetic energy

$\mathrm{E_F}$ - Energy dissipated by contact friction forces between the contact surfaces

$\mathrm{E_W}$ - Work of a body by external forces

$\mathrm{E_{QB}}$ - Energy dissipated by the damping effect of solid medium infinite elements

σ^{υ} - Viscous stress

σ^{c} - Stress derived of a constitutive equation

$\dot{\varepsilon}^{el}$ - Elastic strain rate

$\dot{\varepsilon}^{pl}$ - Plastic strain rate

$\dot{\varepsilon}^{cr}$ - Creep strain rate

$\mathrm{E_S}$ - Applied elastic strain energy

$\mathrm{G_U}$ - Internal energy

$\mathrm{G_E}$ - Strain energy

$\mathrm{G_D}$ - Dissipated energy

LIST OF TERMINOLOGIES

Multi-damage or -failure	-	Various types of damage or failure events that occur in a FRP lamina as a solid continuum part.
Multi-delamination	-	Occurrence of several delamination events in FRP composite laminates.
Multiple damage, failure, fracture or crack	-	Simultanious occurrence of several damage, Failure, fracture or cracking events in intralaminar and interlaminar constituents of FRP composite laminates.
Crack-jump phenomenon	-	An initial interlaminar crack in FRP composite laminate under mode I or II loading condition, which propagated suddenly with large size.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Fiber-reinforced polymer (FRP) composite laminate materials are increasingly replaced by metal materials in advanced structural application in defense, transport and etc. industries. Therefore, a correct comprehension about failure phenomena in FRP composite is necessary for the design and analysis of such structures. The knowledge of failure in composites normally obtained using numerical and experimental approaches. The experimental procedures normally are expensive and time consuming for complex loading condition which rarely can be used for design stages of composite structures. The numerical methods involve the mathematical derivation of structural behavior, failure phenomena and energy absorption of composites, which normally provide a deeper insight on structural failure for the design phase, however it is incomplete to define a response map of the three-dimensional (3D) structures. In the past three decades, development of *Simulation Methodologies* has been considered as one of the most effective method in bridging the mathematical models and experiments for realistic design and analysis of advanced industrial structures. Simulation procedures are benefit scientists to characterize the mechanical properties, to define the response map, and to enhance the final design of the composite structures using the lowest number of expensive samples and tests.

At the current state of development, an extensive analytical models have been introduced for numerical investigation of failure in composites, however the simulation methodology in prediction of complex multiple failure is still considered as an open topic for investigation. The present study uses the finite element method (FEM) as the most used approach, to develop a simulation methodology for prediction of multiple failure in multidirectional FRP composite laminates. The theory of continuum damage mechanics is used to develop the constitutive models for prediction of elastic-damage and fracture behaviors. Simulation of several tests on unidirectional/multidirectional FRP composites with and without pre-cracks are performed to examine the considered models and the methodology procedure.

1.2 Problem Background and Rationale

In the past few decades, advanced industries demand for materials with both light and strong features has been the main force to develop composite materials (Dempster D., 2003; Taylor, 2008). Advanced composite materials are constructed of two or more separate phases, mainly consisted of matrix phase, reinforcement phases and matrix/reinforcement interface that is known as interphase region. Fiber Reinforced Polymer (FRP) composites as one of the important advanced composites are created using polymeric matrix phase (thermoplastic, thermoset and etc.) which typically reinforced with fibrous (glass, carbon, aramid and etc.) materials. The design flexibility of FRP laminate composites through variation of matrix/reinforcement phase types, adjustment of reinforcement volume fraction in micro-scale and modification of laminas orientation in meso-scale, highlighted the capability of these materials for creation of superstructures with preferable solidity in various directions. The great advantages of FRP composites including high stiffness-strength combined with low weight bring a steady increase of investment in transport, aerospace and green industries on continuous replacement of metallic structures to composites. For this reason, the development of reliable and well-validated mathematical-physical models to describe the linear and nonlinear behavior of composites, become essential. Therefore, development of continuum damage model (CDM) for anisotropic material is important (Baker et al., 2004; Kaw, 1997; S. Murakami, 2012).

Mechanics of FRP composite materials is classified based on the level of the analysis in micro-, meso- or macro-scales. Therefore, damage and failure analyses of composite structures are practiced in different scales too. In this respect, the influences of mechanical features and properties in the microstructure of lamina have to be considered in the constitutive elastic-damage model parameters when it viewed in meso-macro scales too. Therefore, bridging between micro-to-macro mechanics is always one of the factors that is used prediction of mechanical behavior in composite materials (Baker, et al., 2004; R. Talreja and Singh, 2012).

In constructional view, FRP composites are created with a soft polymeric phase that is reinforced with stiff fibrous phase with almost 30-95% (e.g. Typical glass fiber reinforced polymer (GFRP), carbon fiber reinforced polymer (CFRP)) elastic-stiffness properties differences. Likewise, the anisotropic strength of the FRP composites normally shows up to 90% difference in the fiber direction compared with transverse to the fiber direction. Such big differences in elastic-strength properties accelerate early failure in weaker phases while structural performance is considered to be in the safe zone. In a FRP composite structure, fibers are assumed to be responsible for load bearing due to high stiffness, but in the other hand consideration of Poisson's ratio influences as a part of anisotropic continuum behavior is undeniable. Therefore, occurrence of matrix failure in high strength FRP composites such as CFRP is likely, which has to be considered as one the factors in design FRP composite structures. Therefore, understanding of yielding phenomena in composite lamina in meso-scale and laminate in macro-scale and also the related criteria with respect to yield surface is important. The present study, is attempting to introduce an overall yielding point in FRP *lamina* and *laminate*, using damage mechanics concept by considering a certain value of accumulated irrecoverable energy in the structure over total damage dissipation energy (Dempster D., 2003; R. Talreja and Singh, 2012; Taylor, 2008).

Most of the existing knowledge of damage and failure in FRP composites obtained through experimental and numerical methods. Normally, experimental data are limited due to the high value of cost for tests implementation and less diversity of data which rarely can be utilized in earlier design methods. In the other hand, internal analysis of structures in terms of deformation and damage zone is hardly possible, which most of the time considered as important knowledge that have to be obtained for design and analysis of composite superstructures. Numerical methods are normally cost saving in comparison with the experimental method, which is enabling a huge amount of data on mechanical parameters that lead to a deep insight into the design and failure analysis of composite structure. In the other hand, once a model is established, it could be used for various analyses, including different types of loads and boundary conditions. These results can be used in defining the responses map of the material as a support for enhancing the final design of the structure at low cost (Baker, et al., 2004; R. Talreja and Singh, 2012). However, at the current state, numerical models are not developed fully to cover the failure behavior of composite materials under complex loading condition. Several constitutive elastic-damage models based on continuum mechanics approach are derived to overcome this challenge, including a series of studies called the worldwide failure exercises (WWFE) that is made to describe the foremost theories for FRP composites (Chamis et al., 2013; Hinton, Kaddour and Soden, 2004; Kaddour et al., 2013; Labeas et al., 2011; Varna, 2013). In this exercise, a huge number of comparisons have been made on the capability of different mathematical models in order to predict the evolution of damage and failure events under various types of loading consist of biaxial, bending, thermal loadings and loading-unloading condition (Hinton, et al., 2004; Kaddour, et al., 2013). Several approaches including multi-scale hybrid damage and failure (Laurin et al., 2013), micromechanics based model (Chamis, et al., 2013), shear lag and equivalent constraint model (Kashtalyan and Soutis, 2013), enhanced damage meso-model (Daghia and Ladeveze, 2013), energy methodology (McCartney, 2013a, 2013b), constitutive damage model (Schuecker and Pettermann, 2013), plasticity-based theory (S. Pinho, Vyas and Robinson, 2013), classical damage model (Sapozhnikov and Cheremnykh, 2013), synergistic damage mechanics (Singh and Talreja, 2013), global-local cracking approach (Varna, 2013), structural damage modeling framework (Forghani et al., 2013) and its, are used to make comparison between the models and the experimental data. The conclusion of this research was that, out of 12 leading theories and 13 challenging tests for prediction of failure evolution, "*Only three groups solved all the 13 challenging problems and approximately 30% of the test cases were not solved*" (Kaddour, et al., 2013). It is noted that in general, the lack of consensus appears regarding the effects of ply thickness and lay-up sequences, influences of unloading-reloading behavior, and interaction in multiple crack locations and matrix crack-delamination (Kaddour, et al., 2013). Miscomprehension of the complex physics of FRP composite failure also commented as one of the reasons for low accuracy in prediction of failure (Silvestre Taveira Pinho, 2005). Most of the mathematical models are stress-based models computed at local material point through damage criteria to address the local failure process. Variation of effective stresses in FRP composites depend on assumed construction based on FEM and also the theoretical basis. One of the aspects, which have not been paid enough attention, is the influences of manufacturing processes in micro-meso construction of FRP composites through computational method. The present work investigated on the finite element (FE)-based model construction that could represent the actual construction of the composite created through different fabrication processes. This point is recommended for further investigation in previous works as multi-layer modeling methodology for failure analysis of FRP laminate composites (Kaddour, et al., 2013; Siromani, 2013). In other study, investigation on the physical properties reduction of composite structure due to damage and multiple failure is recommended for future work (Lasn, 2015). Full set of CDMs is reviewed and applied to address the progressive damage processes of FRP composites. FEM as an affective approximate method is used for predicting the complex response of composite structures. Implementation procedure of FEM is described extensively through a hybrid experimental-computational approach in order to combine the FE and test data for a comprehensive understanding of the failure process. Emphasis is placed on engineering aspects, such as the analytical descriptions, effective analysis tools, modeling of physical features and evaluation of approaches used to formulate and predict the actual response of composite structures (Ochoa and Reddy, 1992).

1.3 Statement of the Research Problem

How to identify and characterize the fracture processes of FRP laminate composites using damage-based models and finite element method under quasi-static monotonic loads?

1.4 Research Questions

The relevant research questions to the problem statement of the present study can be sorted out as follow:

1. What are the dominant damage mechanisms of FRP composites?
2. What models are suitable for simulating the observed linear-nonlinear deformation and fracture of FRP composites?
3. How does damage, initiate and propagate in matrix, interface and fiber of FRP composites?
4. How to evaluate the mechanics and mechanism of multiple damage processes (matrix cracking/crushing, multi-delamination and fiber breakage/buckling) in FRP composite materials under quasi-static monotonic loading condition?
5. How would the damage models and failure process be validated?

1.5 Objectives of Study

The aims of the present study are to develop a validated simulation methodology for failure processes of the FRP laminate composite under quasi-static monotonic loads. In this respect, the objectives of the study are defined in the main fields of mathematical-physical modeling, FE simulation and experimental works to solve the problem, which are develop and completed in the next chapters. The objectives are linked and highlighted throughout the research in the result and discussion chapters, which a short summery of them is listed in the conclusion remarks (Chapter 8).

The specific objectives of this study are:

1. To develop and derive bilinear physically-based damage model for FRP lamina.
2. To establish FE-based model constructions of FRP composite based on different manufacturing processes.
3. To identify the mechanics and mechanism of failure of FRP laminate composites under quasi-static loading.
4. To investigate on the effect of different constructions on the progressive damage processes of FRP laminate composites
5. To predict the elastic-plastic behavior and mechanism of multiple failure in FRP composite beams under flexural loading.
6. To represent the FE implementation of damage and failure in FRP composite using a hybrid experimental-computational approach.
7. To validate the damage-based FE model using experimental results.

1.6 Scope of Study

The present study is concentrating on the simulation methodology to identify and characterize the mechanics and mechanisms of failure in FRP laminate composites under monotonic loading condition. The scope of this research is restricted to unidirectional FRP laminate composites as:

1. Only, the two manufacturing processes of Prepreg/Autoclave method and vacuum infusion process (VIP) are considered, to fabricate multidirectional FRP composite laminates.
2. To prepare CFRP composite manufactured using Prepreg/Autoclave method, with uni/multi-directional ply sequences, and with/without pre-crack.
3. To manufacture anti-symmetric GFRP composites using VIP method, and machining into beam samples for mechanical test.
4. To perform mechanical tests on the FRP composite beams, to obtain the structural response and mechanical properties as follow:
    a. Three and four-point bending tests on anti-symmetric CFRP and GFRP composite laminates.
    b. Double cantilever beam (DCB) and end-notched flexure (ENF) tests on CFRP composite to obtain the critical fracture energy of interface in modes I & II loading condition.
    c. To perform critical ENF test on a specially designed specimen to capture unstable crack-jump.
5. To identify the various types of intralaminar and interlaminar fracture events in FRP composite laminates, using fractographic investigation on the tests performed in the above cases (No. 3).
6. To develop and describe the theories as bilinear CDMs for FRP lamina and interface.
7. To create FE models using ABAQUS 6.9EF software, in order to simulate the following cases:
    a. To develop FE model-based constructions that represent the construction of FRP composite laminates, which are manufactured using VIP and Prepreg/Autoclave methods.
    b. To develop individual FE models of FRP composite laminate, to simulate laminas failure using CDM, and also interface delamination using cohesive zone model (CZM).
    c. To develop a FE model that comprises both CDM and CZM models to simulate multiple fracture in CFRP composite laminates manufactures using Prepreg/Autoclave methods.

8. To validate the damage theories and FE models (above cases, No. 6) using experimental data, in both aspects of mechanics and mechanism of damage.
9. To establish the simulation methodology for fracture processes of FRP composites using hybrid experimental-computational approach throughout of the present study.

1.7 Layout of the Thesis

In this thesis, chapters are arranged to address the FE simulation methodology for prediction of the mechanics and mechanism failure in FRP laminate composites. Assessment of progressive multiple damage processes through laminas and the interface of the composite are the main interest. In this respect, the content of the chapters is classified to explain the objectives and scope of the research as follow.

Chapter 1 gives an overview on the background of laminate composites and the challenges in simulation and analysis for real applications. Then the problem statement, objectives and the scope of the research are described. The limits of what this study is restricted to, are notified.

Chapter 2 provides a summary of the literature and previous researches about FRP composite specification, properties and manufacturing methods. The applications of FRP composites in advanced industries are investigated. The use of FEM in simulation of mechanical cases is studied. A brief description of the mechanics deformation and mechanism of failure in FRP composite laminates is provided. Continuum damage mechanics of composite materials are explained to represent a physical view of the damage phenomena. The various modes of failure in FRP composite are studied, and the related damage models, available numerical tools and FE procedures to estimate and predict damage modes are described. Multiple failure phenomena in FRP composite are demonstrated using fractographic image of a CFRP beam sample under tension loading condition. The missing points and the gaps to previous researches are highlighted.

Chapter 3 discusses about research methodology of the present work. The research framework of the study is provided based on the three activities of modeling, computation and experiment. Types of the specimen, test procedure and the related material properties are provided. The steps for FE simulation of a composite system are described. The manufacturing issues of FRP composite laminates and the related FE model-based constructions are discussed. A hybrid experimental-computational approach is introduced, which is used entirely through the research investigation. The basis of FE implementation of the damage and fracture analyses on different FE constructions of FRP composite is described.

In *chapter 4*, the physically-based continuum models for prediction of multiple failures of FRP laminate composites are described. The phenomena of CDM of lamina and its physical interpretation is discussed. The physical influences of interlaminar region are described for the modeling of FRP composites in the conditions, where perfect laminas bonding or interface debonding are targeted. FE implementation of the model is illustrated through FE simulation by describing the evolution of effective stresses and variation of damage parameters.

Chapter 5 illustrates the FE simulation methodology of FRP composite lamina by introducing specific FE based-model construction for different manufacturing processes. The influences of different constructions in the computation of progressive intralaminar damage process are described. The validated FE models are used to describe the mechanics of system response and mechanisms of multi-damage processes in FRP composite laminates.

Chapter 6 works on the mechanics of interface delamination in CFRP composite in the presence of initial crack. Experimental investigation on CFRP composite under mode-I test is provided (DCB Test) to discuss about delamination phenomenon. FE simulation and experiment of CFRP composite under mode-II loading is provided (ENF test) to study on the mechanism of interface delamination using CZM theory. The capability of the governing law in prediction of the crack growth and crack-jump phenomena are examined. The concept of stable and unstable crack-jump is developed.

Chapter 7 demonstrates the FE simulation methodology for prediction of multiple failure events in FRP composites by applying CDM and CZM theories in intralaminar/interlaminar parts. The predictive capability of these models in the simultaneous prediction of various failure modes in the lamina and interface of anti-symmetric multidirectional CFRP specimen is examined under four-point bending load condition. Validation of the damage mechanics and mechanism of failure is the main concern.

Chapter 8 explains the conclusion related to the FE simulation methodology and failure mechanism of FRP composites in the present study. The future work on the development of the failure models for fatigue mechanics and etc. of FRP composites are recommended.

REFERENCES

Aboudi, J., Arnold, S. M. and Bednarcyk, B. A. (2013). *Micromechanics of Composite Materials: A Generalized Multiscale Analysis Approach*: Butterworth-Heinemann.

Abumeri, G. H., Kosareo, D. N. and Roche, J. M. (2004). Cryogenic composite tank design for next generation launch technology. *AIAA*, 3390, 2004.

Accardo, A., Ricci, F. and Basso, P. (2001). Design, Realisation and Testing of an Advanced Composite Unmanned Aircraft. Proceedings of the 2001 *Proceedings of the 13th International Conference on Composite Materials, Beijing, China*,

Ahn, S.-H., Montero, M., Odell, D., Roundy, S. and Wright, P. K. (2002). Anisotropic material properties of fused deposition modeling ABS. *Rapid Prototyping Journal*, 8(4), 248-257.

Akula, V. and Garnich, M. (2012). Effective ply and constituent elastic properties for cracked laminates. *Composites Part B: Engineering*, 43(5), 2143-2151.

Alfano, G. and Crisfield, M. (2001). Finite element interface models for the delamination analysis of laminated composites: mechanical and computational issues. *International journal for numerical methods in engineering*, 50(7), 1701-1736.

Altenbach, H., Altenbach, J. W. and Kissing, W. (2004). *Mechanics of composite structural elements*: Springer Science & Business Media.

Altenbach, H. and Sadowski, T. (2014). *Failure and Damage Analysis of Advanced Materials*: Springer Vienna.

Anghileri, M., Castelletti, L.-M. L., Francesconi, E., Milanese, A. and Pittofrati, M. (2014). Survey of numerical approaches to analyse the behavior of a composite skin panel during a water impact. *International Journal of Impact Engineering*, 63, 43-51.

Antonucci, V. and Zarrelli, M. (2015). Vacuum Infusion Manufacturing of CFRP Panels with Induced Delamination *Damage Growth in Aerospace Composites* (pp. 249-261): Springer.

Arai, M., Matsushita, K. and Hirota, S. (2011). Criterion for interlaminar strength of CFRP laminates toughened with carbon nanofiber interlayer. *Composites Part A: Applied Science and Manufacturing*, 42(7), 703-711.

Ashby, M. F. (2004). *Materials Selection in Mechanical Design*: Elsevier Science.

Aslan, Z. and Alnak, Y. (2010). Characterization of interlaminar shear strength of laminated woven E-glass/epoxy composites by four point bend shear test. *Polymer Composites*, 31(2), 359-368.

ASTM-D4762-11a. (2011). Standard Guide for Testing Polymer Matrix Composite Materials. West Conshohocken: ASTM International.

ASTM-D5528-01. (2001). tandard Test Method for Mode I Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites. West Conshohocken,: ASTM International.

ASTM-D7264/D7264M-07. (2007). Standard Test Method for Flexural Properties of Polymer Matrix Composite Materials. West Conshohocken: ASTM International.

ASTM-D7905/D7905M-14. (2014). Standard Test Method for Determination of the Mode II Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites. West Conshohocken: ASTM International.

Azzi, V. and Tsai, S. (1965). Anisotropic strength of composites. *Experimental mechanics*, 5(9), 283-288.

Bai, Y. and Zhang, C. (2012). Capacity of nonlinear large deformation for trusses assembled by brittle FRP composites. *Composite Structures*, 94(11), 3347-3353. doi: http://dx.doi.org/10.1016/j.compstruct.2012.05.016

Baker, A. A., Dutton, S., Kelly, D. and Kelly, D. W. (2004). *Composite materials for aircraft structures*: American Institute of Aeronautics and Astronautics.

Bakis, C. E., Testing, A. S. f., Materials and Materials, A. C. D.-o. C. (2003). *Composite Materials: Testing and Design, Fourteenth Volume*: ASTM.

Barenblatt, G. I. (1962). The mathematical theory of equilibrium cracks in brittle fracture. *Advances in applied mechanics*, 7(55-129), 104.

Batra, R. and Hassan, N. (2008). Blast resistance of unidirectional fiber reinforced composites. *Composites Part B: Engineering*, 39(3), 513-536.

Beaumont, P., Soutis, C. and Hodzic, A. (2015). *Structural Integrity and Durability of Advanced Composites: Innovative Modelling Methods and Intelligent Design*: Elsevier Science.

Belingardi, G. and Koricho, E. G. (2012). AN EXPERIMENTAL AND FINITE ELEMENT STUDY OF THE TRANSVERSE BENDING BEHAVIOR OF T-JOINTS IN VEHICLE STRUCTURES.

Benzeggagh, M. and Kenane, M. (1996). Measurement of mixed-mode delamination fracture toughness of unidirectional glass/epoxy composites with mixed-mode bending apparatus. *Composites Science and Technology*, 56(4), 439-449.

Berthelot, J. M. and Cole, J. M. (2012). *Composite Materials: Mechanical Behavior and Structural Analysis*: Springer New York.

Bettini, P., Airoldi, A., Sala, G., Di Landro, L., Ruzzene, M. and Spadoni, A. (2010). Composite chiral structures for morphing airfoils: Numerical analyses and development of a manufacturing process. *Composites Part B: Engineering*, 41(2), 133-147.

Bianchi, F., Koh, T., Zhang, X., Partridge, I. and Mouritz, A. (2012). Finite element modelling of z-pinned composite T-joints. *Composites Science and Technology*, 73, 48-56.

Boisse, P. (2015). *Advances in Composites Manufacturing and Process Design*: Elsevier Science.

Bondyra, A., Klasztorny, M. and Muc, A. (2015). Design of Composite Tank Covers. *Composite Structures*. doi: http://dx.doi.org/10.1016/j.compstruct.2015.07.008

Borkowski, L., Liu, K. and Chattopadhyay, A. (2014). Micromechanics Model to Link Microstructural Variability to Fiber Reinforced Composite Behavior.

Boscolo, M. and Banerjee, J. (2012). Dynamic stiffness formulation for composite Mindlin plates for exact modal analysis of structures. Part II: Results and applications. *Computers & Structures*, 96, 74-83.

Botkin, M., Johnson, N., Zywicz, E. and Simunovic, S. (1998). Crashworthiness simulation of composite automotive structures. Proceedings of the 1998 *13th annual engineering society of detroit advanced composites technology conference and exposition, Detroit*, Brewer, J. C. and Lagace, P. A. (1988). Quadratic stress criterion for initiation of delamination. *Journal of composite materials*, 22(12), 1141-1155.

Broughton, W., Gower, M., Lodeiro, M., Pilkington, G. and Shaw, R. (2011). An experimental assessment of open-hole tension–tension fatigue behaviour of a GFRP laminate. *Composites Part A: Applied Science and Manufacturing*, 42(10), 1310-1320.

Cai, X., Zhu, J., Pan, P. and Gu, R. (2012). Structural optimization design of horizontal-axis wind turbine blades using a particle swarm optimization algorithm and finite element method. *Energies*, 5(11), 4683-4696.

Camanho, P. P. and Dávila, C. G. (2002a). Mixed-mode decohesion finite elements for the simulation of delamination in composite materials.

Camanho, P. P. and Dávila, C. G. (2002b). Mixed-mode decohesion finite elements for the simulation of delamination in composite materials. *NASA-Technical paper*, 211737(1), 33.

Cambridge, U. o., from http://www-materials.eng.cam.ac.uk/mpsite/interactive_charts/spec-spec/basic.html

Caprino, G., Halpin, J. and Nicolais, L. (1979). Fracture mechanics in composite materials. *Composites*, 10(4), 223-227.

Carlsson, L. A., Adams, D. F. and Pipes, R. B. (2014). *Experimental characterization of advanced composite materials*: CRC press.

Chaboche, J. (1977). Sur l’utilisation des variables d’état interne pour la description du comportement viscoplastique et de la rupture par endommagement. Proceedings of the 1977 *Proc. Problemes non-linéaires de mécanique, Symposium franco-polonais, Cracow (Poland)*, 137-159.

Chaboche, J. (1982). The concept of effective stress applied to elasticity and to viscoplasticity in the presence of anisotropic damage. *In: Boehler JP (ed) Mechanical behavior of anisotropic solids (Proceedings of Euromech Colloquium 115, Grenoble 1979)*, 737–760.

Chamis, C. C., Abdi, F., Garg, M., Minnetyan, L., Baid, H., Huang, D., et al. (2013). Micromechanics-based progressive failure analysis prediction for WWFE-III composite coupon test cases. *Journal of Composite Materials*, 0021998313499478.

Chang, F.-K. and Chang, K.-Y. (1987). A progressive damage model for laminated composites containing stress concentrations. *Journal of Composite Materials*, 21(9), 834-855.

Chang, F.-K. and Lessard, L. B. (1991). Damage tolerance of laminated composites containing an open hole and subjected to compressive loadings. I: Analysis. *Journal of Composite Materials*, 25(1), 2-43.

Chang, R. R., Dai, W. J., Wu, F. Y., Jia, S. Y. and Tan, H. M. (2013). Design and Manufacturing of a Laminated Composite Bicycle Crank. *Procedia Engineering*, 67, 497-505. doi: http://dx.doi.org/10.1016/j.proeng.2013.12.050

Che, D., Saxena, I., Han, P., Guo, P. and Ehmann, K. F. (2014). Machining of carbon fiber reinforced plastics/polymers: A literature review. *Journal of Manufacturing Science and Engineering*, 136(3), 034001.

Chen, J.-F., Morozov, E. V. and Shankar, K. (2014). Progressive failure analysis of perforated aluminium/CFRP fibre metal laminates using a combined elastoplastic damage model and including delamination effects. *Composite Structures*, 114, 64-79.

Chen, M. C., AJ Kinloch, EP Busso, FL Matthews, Y. Qiu, J. (1999). Predicting progressive delamination of composite material specimens via interface elements. *Mechanics of composite materials and structures*, 6(4), 301-317.

Chow, C. and Lu, T. (1989). A normative representation of stress and strain for continuum damage mechanics. *Theoretical and applied fracture mechanics*, 12(2), 161-187.

Christensen, R. (1997). Stress based yield/failure criteria for fiber composites. *International journal of solids and structures*, 34(5), 529-543.

Christensen, R. M. (1988). Tensor transformations and failure criteria for the analysis of fiber composite materials. *Journal of Composite Materials*, 22(9), 874-897.

Comer, A., Katnam, K., Stanley, W. and Young, T. (2013). Characterising the behaviour of composite single lap bonded joints using digital image correlation. *International Journal of Adhesion and Adhesives*, 40, 215-223.

Cottrell, A. (1964). The Mechanical Properties of Matter: Wiley, New York Library of Congress.

Cowin, S. C. (2013). *Continuum Mechanics of Anisotropic Materials*: Springer.

Cui, W., Wisnom, M. and Jones, M. (1992). A comparison of failure criteria to predict delamination of unidirectional glass/epoxy specimens waisted through the thickness. *Composites*, 23(3), 158-166.

Cuntze, R. and Freund, A. (2004). The predictive capability of failure mode concept-based strength criteria for multidirectional laminates. *Composites Science and Technology*, 64(3), 343-377.

Daghia, F. and Ladeveze, P. (2013). Identification and validation of an enhanced mesomodel for laminated composites within the WWFE-III. *Journal of Composite Materials*, 47(20-21), 2675-2693.

Dangora, L., Sherwood, J. and Mitchell, C. (2014). Application of a Discrete Mesoscopic Finite Element Approach to Investigate the Bending and Folding of Fiber-Reinforced Composite Materials during the Manufacturing Process. Proceedings of the 2014 *Key Engineering Materials*, 324-331.

Daniel, I. M. (2006). *Engineering mechanics of composite materialsi* (2nd ed.): Oxford Univerisity Press. New York.

Daniel, I. M. and Ishai, O. (2006). *Engineering Mechanics of Composite Materials*: Oxford University Press.

Darabi, M. K., Al-Rub, R. K. A. and Little, D. N. (2012). A continuum damage mechanics framework for modeling micro-damage healing. *International Journal of Solids and Structures*, 49(3), 492-513.

Davidson, B. D. and Zhao, W. (2007). An accurate mixed-mode delamination failure criterion for laminated fibrous composites requiring limited experimental input. *Journal of composite materials*, 41(6), 679-702.

Davies, P., Moulin, C., Kausch, H. and Fischer, M. (1990). Measurement of G IC and G IIC in carbon/epoxy composites. *Composites Science and Technology*, 39(3), 193-205.

Dávila, C. G. and Camanho, P. P. (2003a). Analysis of the effects of residual strains and defects on skin/stiffener debonding using decohesion elements. Proceedings of the 2003a *Proc. 44th AIAA/ASME/ASCE/AHS structures, structural dynamics, and materials conf. Norfolk, VA,*

Dávila, C. G. and Camanho, P. P. (2003b). Failure criteria for FRP laminates in plane stress. *NASA TM*, 212663(613).

Dávila, C. G., Camanho, P. P. and de Moura, M. F. (2001). Mixed-mode decohesion elements for analyses of progressive delamination. Proceedings of the 2001

Proceedings of the 42nd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference, Seattle, WA,

Dempster, D. (2003). Flight Airworthiness Support Technology (FAST). *AIRBUS Technical Digest*.

Dempster D., M.-L. A. (2003). *Flight airworthiness support technology (FAST) 32*. AIRBUS technological digest, (32).

Dharan, C. (1978). Fracture mechanics of composite materials. *Journal of engineering materials and technology*, 100(3), 233-247.

Díaz, J. and Rubio, L. (2003). Developments to manufacture structural aeronautical parts in carbon fibre reinforced thermoplastic materials. *Journal of Materials Processing Technology*, 143–144, 342-346. doi: http://dx.doi.org/10.1016/S0924-0136(03)00450-3

DoE, U. (2011). Quadrennial Technology review (pp. 39): US Department of Energy.

DoE, U. (2015). Advanced Composites Materials and their Manufacture Technology Assessment: US Department of Energy.

Donaldson, S. (1985). Fracture toughness testing of graphite/epoxy and graphite/PEEK composites. *Composites*, 16(2), 103-112.

Dong, C. (2010). Process-induced deformation of composite T-stiffener structures. *Composite Structures*, 92(7), 1614-1619.

Drechsler, K., Heine, M., Mitschang, P., Baur, W., Gruber, U., Fischer, L., et al. (2009). Carbon fiber reinforced composites. *Ullmann's Encyclopedia of Industrial Chemistry*.

Duffy, K. and Adali, S. (1990). Design of antisymmetric hybrid laminates for maximum buckling load: II. Optimal layer thickness. *Composite structures*, 14(2), 113-124.

Dvorak, G. (2012). *Micromechanics of Composite Materials*: Springer Netherlands.

E, P. and Soutis, C. (2014). *Polymer Composites in the Aerospace Industry*: Elsevier Science.

Echaabi, J. and Trochu, F. (1997). Failure mode dependent strength criteria for composite laminates. *Journal of reinforced plastics and composites*, 16(10), 926-945.

Ellobody, E. (2011). Performance of composite girders strengthened using carbon fibre reinforced polymer laminates. *Thin-Walled Structures*, 49(11), 1429-1441.

Elmarakbi, A. (2013). *Advanced Composite Materials for Automotive Applications: Structural Integrity and Crashworthiness*: Wiley.

Erkal, S., Sayman, O., Benli, S., Dogan, T. and Cinar Yeni, E. (2010). Fatigue damage in composite cylinders. *Polymer Composites*, 31(4), 707-713.

Feito, N., López-Puente, J., Santiuste, C. and Miguélez, M. (2014). Numerical prediction of delamination in CFRP drilling. *Composite Structures*, 108, 677-683.

Forghani, A., Zobeiry, N., Poursartip, A. and Vaziri, R. (2013). A structural modelling framework for prediction of damage development and failure of composite laminates. *Journal of Composite Materials*, 0021998312474044.

Frizzell, R. M., McCarthy, C. T. and McCarthy, M. A. (2011). Predicting the effects of geometry on the behaviour of fibre metal laminate joints. *Composite Structures*, 93(7), 1877-1889. doi: http://dx.doi.org/10.1016/j.compstruct.2011.01.018

Gallagher, J. N. (2008). *Manufacturing of Transparent Composites Using Vacuum Infusion Process*.

Garcia, E. J., Wardle, B. L. and John Hart, A. (2008). Joining prepreg composite interfaces with aligned carbon nanotubes. *Composites Part A: Applied Science and Manufacturing*, 39(6), 1065-1070.

Gay, D. (2014). *Composite Materials: Design and Applications, Third Edition*: Taylor & Francis.

Gdoutos, E. E. (2007). *Experimental Analysis of Nano and Engineering Materials and Structures: Proceedings of the 13th International Conference on Experimental Mechanics, Alexandroupolis, Greece, July 1-6, 2007*: Springer.

Gdoutos, E. E., Pilakoutas, K. and Rodopoulos, C. (2000). *Failure analysis of industrial composite materials*: McGraw-Hill Professional.

Geiringer, H. (1937). Fondements mathématiques de la théorie des corps plastiques isotropes.

Ghelli, D. (2009). *Some issues concerning the dynamic response and damage of composite laminates subjected to low velocity impact.* Doctoral dissertation, University of Bologna, Alma Mater Studiorum.

Ghezeljeh, P. N. and Pineda, E. J. (2014). Simulating Damage Due to a Lightning Strike Event: Effects of Temperature Dependent Properties on Interlaminar Damage. *Paper presented at the Simulia Community Conference 2014*, United States.

Gooch, J. (2007). Encyclopedic dictionary of polymers. *Atlanta, USA: Springer Science+ Business Media*, 200, 772.

Gosse, J. H. and Christensen, S. (2001). Strain invariant failure criteria for polymers in composite materials. *AIAA*, 1184, 11.

Goyal, V. K., Johnson, E. R. and Davila, C. G. (2004). Irreversible constitutive law for modeling the delamination process using interfacial surface discontinuities. *Composite Structures*, 65(3), 289-305.

Greszczuk, L. (1974). Microbuckling of lamina—reinforced composites. *Composite Materials: Testing and Design*, 3.

Griffith, A. A. (1921). The phenomena of rupture and flow in solids. *Philosophical transactions of the royal society of london. Series A, containing papers of a mathematical or physical character*, 163-198.

Groover, M. P. (2010). *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems*: John Wiley & Sons.

Grujicic, M., Arakere, G., Sellappan, V., Ziegert, J., Koçer, F. and Schmueser, D. (2009). Multi-disciplinary design optimization of a composite car door for structural performance, NVH, crashworthiness, durability and manufacturability. *Multidiscipline Modeling in Materials and Structures*, 5(1), 1-28.

Guades, E., Aravinthan, T., Manalo, A. and Islam, M. (2013). Damage modelling of repeatedly impacted square fibre-reinforced polymer composite tube. *Materials & Design*, 47, 687-697.

Gulasik, H. and Coker, D. (2014). Delamination-Debond Behaviour of Composite T-Joints in Wind Turbine Blades. Proceedings of the 2014 *Journal of Physics: Conference Series*, 012043.

Gunes, O. (2013). 5 - Failure modes in structural applications of fiber-reinforced polymer (FRP) composites and their prevention. In N. Uddin (Ed.), *Developments in Fiber-Reinforced Polymer (FRP) Composites for Civil Engineering* (pp. 115-147): Woodhead Publishing.

Hahn, H. (1983). A mixed-mode fracture criterion for composite materials. *Composites Technology Review*, 5(1), 26-29.

Hahn, H. and Johannesson, T. (1984). A correlation between fracture energy and fracture morphology in mixed-mode fracture of composites. *Mechanical behaviour of materials- IV*, 431-438.

Hahn, H. T. and Williams, J. G. (1986). Compression failure mechanisms in unidirectional composites. *Composite Materials: Testing and Design*, 115-139.

Hallett, S. R., Jiang, W.-G., Khan, B. and Wisnom, M. R. (2008). Modelling the interaction between matrix cracks and delamination damage in scaled quasi-isotropic specimens. *Composites Science and Technology*, 68(1), 80-89.

Hansen, A. C. and Garnich, M. R. (1995). A multicontinuum theory for structural analysis of composite material systems. *Composites Engineering*, 5(9), 1091-1103.

Hansen, A. C., Kenik, D. J. and Nelson, E. E. (2009). Multicontinuum failure analysis of composites. Proceedings of the 2009 *17th International Conference on Composite Materials*,

Harizi, W., Chaki, S., Bourse, G. and Ourak, M. (2014). Mechanical damage assessment of Glass Fiber-Reinforced Polymer composites using passive infrared thermography. *Composites Part B: Engineering*, 59, 74-79.

Hart-Smith, L. (1998). Predictions of the original and truncated maximum-strain failure models for certain fibrous composite laminates. *Composites Science and Technology*, 58(7), 1151-1178.

Hashemi, S., KINLOCH, A. and Williams, G. (1991). Mixed-mode fracture in fiber-polymer composite laminates. *Composite materials: Fatigue and fracture.*, 3, 143-168.

Hashemi, S., Kinloch, A. and Williams, J. (1987). Interlaminar fracture of composite materials. Proceedings of the 1987,

Hashemi, S., Kinloch, A. and Williams, J. (1990). 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*, 24(9), 918-956.

Hashim, S. A. and Nisar, J. A. (2013). An investigation into failure and behaviour of GFRP pultrusion joints. *International Journal of Adhesion and Adhesives*, 40, 80-88. doi: http://dx.doi.org/10.1016/j.ijadhadh.2012.06.002

Hashin, Z. (1980). Failure criteria for unidirectional fiber composites. *Journal of applied mechanics*, 47(2), 329-334.

Hashin, Z. and Rotem, A. (1973). A fatigue failure criterion for fiber reinforced materials. *Journal of composite materials*, 7(4), 448-464.

Heimbs, S., Nogueira, A., Hombergsmeier, E., May, M. and Wolfrum, J. (2014). Failure behaviour of composite T-joints with novel metallic arrow-pin reinforcement. *Composite Structures*, 110, 16-28.

Heimbs, S., Strobl, F., Middendorf, P., Gardner, S., Eddington, B. and Key, J. (2009). Crash simulation of an F1 racing car front impact structure. Proceedings of the 2009 *7th European LS-DYNA users conference, Salzburg,*

Herakovich, C., Aboudi, J., Lee, S. and Strauss, E. (1988a). 2-D and 3-D damage effects in cross-ply laminates. *Mechanics of composite materials- 1988*, 143-147.

Herakovich, C., Aboudi, J., Lee, S. and Strauss, E. (1988b). Damage in composite laminates: effects of transverse cracks. *Mechanics of materials*, 7(2), 91-107.

Hibbs, M. F. and Bradley, W. L. (1987). Correlations between micromechanical failure processes and the delamination toughness of graphite/epoxy systems. *Fractography of modern engineering materials: composites and metals, ASTM STP*, 948, 68-97.

Highsmith, A. L. and Reifsnider, K. L. (1982). Stiffness-reduction mechanisms in composite laminates. *Damage in composite materials*, 775, 103-117.

Hill, R. (1948). A theory of the yielding and plastic flow of anisotropic metals. *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences*, 281-297.

Hinton, M. J., Kaddour, A. S. and Soden, P. D. (2004). *Failure criteria in fibre reinforced polymer composites: the world-wide failure exercise*: Elsevier.

Hoebergen, A. and Holmberg, J. (2001). Vacuum infusion. *Materials Park, OH: ASM International, 2001.*, 501-515.

Hoffman, O. (1967). The brittle strength of orthotropic materials. *Journal of Composite Materials*, 1(2), 200-206.

Hollaway, L. C. (2001). *Advanced Polymer Composites and Polymers in the Civil Infrastructure*: Elsevier Science.

Hu, H.-T., Lin, W.-P. and Tu, F.-T. (2015). Failure Analysis of Fiber-Reinforced Composite Laminates Subjected to Biaxial Loads. *Composites Part B: Engineering*. doi: http://dx.doi.org/10.1016/j.compositesb.2015.08.045

Hu, H., Li, S., Wang, J. and Zu, L. (2015). Structural design and experimental investigation on filament wound toroidal pressure vessels. *Composite Structures*, 121, 114-120. doi: http://dx.doi.org/10.1016/j.compstruct.2014.11.023

Hu, N., Li, Y., Nakamura, T., Katsumata, T., Koshikawa, T. and Arai, M. (2012). Reinforcement effects of MWCNT and VGCF in bulk composites and interlayer of CFRP laminates. *Composites Part B: Engineering*, 43(1), 3-9.

Huang, H., Springer, G. S. and Christensen, R. M. (2003). Predicting failure in composite laminates using dissipated energy. *Journal of composite materials*, 37(23), 2073-2099.

ISO-14125. (1998). Fibre-reinforced plastic composites: Determination of flexural properties.

Johnson, A. F. and Pickett, A. K. (1999). Impact and crash modelling of composite structures: A challenge for damage mechanics. Proceedings of the 1999 *German Aerospace Center DLR Institute of Structures and Design, Stuttgart, Germany, Europ. Conf. on Computational Mechanics, S*,

Kachanov, L. (1958). Time of the rupture process under creep conditions. *Isv. Akad. Nauk. SSR. Otd Tekh. Nauk*, 8, 26-31.

Kachanov, L. (1986). *Introduction to continuum damage mechanics* (Vol. 10): Springer Science & Business Media.

Kaddour, A., Hinton, M., Smith, P. and Li, S. (2013). A comparison between the predictive capability of matrix cracking, damage and failure criteria for fibre reinforced composite laminates: Part A of the third world-wide failure exercise. *Journal of Composite Materials*, 47(20-21), 2749-2779.

Kang, B.-K., Park, J.-S. and Kim, J.-H. (2008). Analysis and optimal design of smart skin structures for buckling and free vibration. *Composite Structures*, 84(2), 177-185.

Kang, K., Chun, H., Na, W., Park, J., Lee, J., Hwang, I., et al. (2011). Optimum design of composite roll bar for improvement of bus rollover crashworthiness. *Elastic*, 1, 141GPa.

Kapidžić, Z., Ansell, H., Schön, J. and Simonsson, K. (2015). Quasi-static bearing failure of CFRP composite in biaxially loaded bolted joints. *Composite Structures*, 125, 60-71. doi: http://dx.doi.org/10.1016/j.compstruct.2015.01.038

Kashtalyan, M. and Soutis, C. (2013). Predicting residual stiffness of cracked composite laminates subjected to multi-axial inplane loading. *Journal of Composite Materials*, 47(20-21), 2513-2524.

Kaw, A. K. (1997). *Mechanics of Composite Materials*: Taylor & Francis.

Kazmi, S., Das, R. and Jayaraman, K. (2014). Sheet forming of flax reinforced polypropylene composites using vacuum assisted oven consolidation (VAOC). *Journal of Materials Processing Technology*, 214(11), 2375-2386.

Kelly, G. (2002). Load Introduction in Carbon Fibre Composites for Automotive Applications.

Kelly, G. and Hallström, S. (2005). Strength and failure mechanisms of composite laminates subject to localised transverse loading. *Composite Structures*, 69(3), 301-314. doi: http://dx.doi.org/10.1016/j.compstruct.2004.07.008

Kepple, K., Sanborn, G., Lacasse, P., Gruenberg, K. and Ready, W. (2008). Improved fracture toughness of carbon fiber composite functionalized with multi walled carbon nanotubes. *Carbon*, 46(15), 2026-2033.

Key, C. T., Garnich, M. R. and Hansen, A. C. (2004). Progressive failure predictions for rib-stiffened panels based on multicontinuum technology. *Composite structures*, 65(3), 357-366.

Kim, C. H. and Yeh, H.-Y. (1994). Development of a new yielding criterion: the Yeh-Stratton criterion. *Engineering fracture mechanics*, 47(4), 569-582.

Kim, J. W. and Lee, D. G. (2006). Fiber orientation state depending on the injection mold gate variations during FRP injection molding. Proceedings of the 2006 *Key Engineering Materials*, 938-941.

Kim, K., Radu, A. G., Wang, X. and Mignolet, M. P. (2013). Nonlinear reduced order modeling of isotropic and functionally graded plates. *International Journal of Non-Linear Mechanics*, 49, 100-110.

Kim, R. and Soni, S. (1986). Failure of composite laminates due to combined interlaminar normal and shear stresses. *Composites*, 86, 341-350.

Ko, H.-Y., Shin, K.-B., Jeon, K.-W. and Cho, S.-H. (2009). A study on the crashworthiness and rollover characteristics of low-floor bus made of sandwich composites. *Journal of mechanical science and technology,* 23(10), 2686-2693.

Koloor, S., Abdul-Latif, A. and Tamin, M. N. (2011). Mechanics of Composite Delamination under Flexural Loading. *Key Engineering Materials*, 462, 726-731.

Koloor, S., Hussin, H. and Tamin, M. (2012). Mode I Interlaminar Fracture Characterization of CFRP Composite Laminates. *Advanced Materials Research*, 488, 552-556.

Koloor, S. S. R., Ayatollahi, M. R. and Tamin, M. N. (2015b). Modelling Interlaminar Shear Crack-Jump Phenomenon in Fiber-Reinforced Polymer Composites. *Advance Material Research*.

Koloor, S. S. R. and Tamin, M. N. (2012). Effects of Lamina Damages on Flexural Stiffness of CFRP Composites. *8th Asian-Australasian Conference on Composite Materials 2012, ACCM 2012 - Composites: Enabling Tomorrow's Industry Today*, 1, 237-243.

Kong, C., Park, H., Lee, H. and Lee, J. (2014). Design of Natural Fiber Composites Chemical Container Using Resin Flow Simulation of VARTML Process.

Krüger, R., Rinderknecht, S. and König, M. (1997). Two-and Three-Dimensional Finite Element Analyses of Crack Fronts in a Multidirectional Composite ENF Specimen: Citeseer.

Kumar, D., Ko, M.-G., Roy, R., Kweon, J.-H., Choi, J.-H., Jeong, S.-K., et al. (2014). AFP mandrel development for composite aircraft fuselage skin. *International Journal of Aeronautical and Space Sciences*, 15(1), 32-43.

Labeas, G., Belesis, S., Diamantakos, I. and Tserpes, K. (2011). Adaptative Progressive Damage Modeling for Large-scale Composite Structures. *International Journal of Damage Mechanics*, 1056789511400928.

Ladeveze, P. (2005). A Bridge Between the Micro-and Mesomechanics of Laminates: Fantasy or Reality? *Mechanics of the 21st Century* (pp. 187-201): Springer.

Ladeveze, P. and LeDantec, E. (1992). Damage modelling of the elementary ply for laminated composites. *Composites Science and Technology*, 43(3), 257-267.

Ladeveze, P. and Lubineau, G. (2002). An enhanced mesomodel for laminates based on micromechanics. *Composites Science and Technology*, 62(4), 533-541.

Laffan, M. J., Pinho, S. T., Robinson, P., Iannucci, L. and McMillan, A. J. (2012). Measurement of the fracture toughness associated with the longitudinal fibre compressive failure mode of laminated composites. *Composites Part A: Applied Science and Manufacturing*, 43(11), 1930-1938. doi: http://dx.doi.org/10.1016/j.compositesa.2012.04.009

Lasn, K. (2015). EVALUATION OF STIFFNESS AND DAMAGE OF LAMINAR COMPOSITES.

Laurin, F., Carrère, N., Huchette, C. and Maire, J.-F. (2013). A multiscale hybrid damage and failure approach for strength predictions of composite structures. *Journal of Composite Materials*, 47(20-21), 2713-2747.

Laws, N. and Dvorak, G. (1987). Transverse matrix cracking in composite laminates *Composite Materials Response: Constitutive Relations and Damage Mechanisms* (pp. 91): Elsevier Applied Science Amsterdam.

Laws, N., Dvorak, G. J. and Hejazi, M. (1983). Stiffness changes in unidirectional composites caused by crack systems. *Mechanics of Materials*, 2(2), 123-137.

Le-Manh, T. and Lee, J. (2014). Stacking sequence optimization for maximum strengths of laminated composite plates using genetic algorithm and isogeometric analysis. *Composite Structures*, 116, 357-363.

Lee, J. D. (1982). Three dimensional finite element analysis of damage accumulation in composite laminate *Fracture of Composite Materials* (pp. 291-306): Springer.

Lehmhus, D., Busse, M., Herrmann, A. and Kayvantash, K. (2013). *Structural Materials and Processes in Transportation*: Wiley.

Lemaitre, J. and CHABOCHE, J.-L. (1978). Aspect phénoménologique de la rupture par endommagement. *J Méc Appl*, 2(3).

Lemaitre, J. and Chaboche, J.-L. (1990). *Mechanics of solid materials*: Cambridge university press.

LI, J. (2002). Three-dimensional effect in the prediction of flange delamination in composite skin-stringer pull-off specimens. *Journal of composites technology & research*, 24(3), 180-187.

Li, J. and Sen, J. K. (2000). Analysis of frame-to-skin joint pull-off tests and prediction of the delamination failure. Proceedings of the 2000 *Proc. 42nd AIAA/ASME/ASCE/AHS/ASC structures, structural dynamics and materials conf. Seattle, WA,*

Li, X., Zou, L., Ni, H., Reynolds, A. P., Wang, C.-a. and Huang, Y. (2008). Micro/nanoscale mechanical characterization and in situ observation of cracking of laminated Si3N4/BN composites. *Materials Science and Engineering: C*, 28(8), 1501-1508. doi: http://dx.doi.org/10.1016/j.msec.2008.04.009

Li, Y., Hori, N., Arai, M., Hu, N., Liu, Y. and Fukunaga, H. (2009). Improvement of interlaminar mechanical properties of CFRP laminates using VGCF. *Composites Part A: applied science and manufacturing*, 40(12), 2004-2012.

Liang, J. and Pochiraju, K. V. (2014). Oxidation-induced damage evolution in a unidirectional polymer matrix composite. *Journal of Composite Materials*, 0021998314534705.

Libonati, F. and Vergani, L. (2013). Damage assessment of composite materials by means of thermographic analyses. *Composites Part B: Engineering*, 50, 82-90.

Lienhard, J. and Böhme, W. (2015). Characterisation of resin transfer moulded composite laminates under high rate tension, compression and shear loading. *Engineering Fracture Mechanics*. doi: http://dx.doi.org/10.1016/j.engfracmech.2015.07.012

Liu, P., Groves, R. M. and Benedictus, R. (2014). 3D monitoring of delamination growth in a wind turbine blade composite using optical coherence tomography. *NDT & E International*, 64, 52-58.

Liu, P., Xing, L. and Zheng, J. (2014). Failure analysis of carbon fiber/epoxy composite cylindrical laminates using explicit finite element method. *Composites Part B: Engineering*, 56, 54-61.

Liu, P. F., Chu, J. K., Liu, Y. L. and Zheng, J. Y. (2012). A study on the failure mechanisms of carbon fiber/epoxy composite laminates using acoustic emission. *Materials & Design*, 37, 228-235. doi: http://dx.doi.org/10.1016/j.matdes.2011.12.015

Lo, D., Allen, D. and Harris, C. (1991). A continuum model for damage evolution in laminated composites *Inelastic Deformation of Composite Materials* (pp. 549-561): Springer.

Long, R. (1991). Static strength of adhesively bonded ARALL-1 joints. *Journal of Composite Materials*, 25(4), 391-415.

Lukaszewicz, D. H. J. A., Ward, C. and Potter, K. D. (2012). The engineering aspects of automated prepreg layup: History, present and future. *Composites Part B: Engineering*, 43(3), 997-1009. doi: http://dx.doi.org/10.1016/j.compositesb.2011.12.003

Luo, Z., Luo, Q., Tong, L., Gao, W. and Song, C. (2011). Shape morphing of laminated composite structures with photostrictive actuators via topology optimization. *Composite Structures*, 93(2), 406-418.

Ma, X., Li, Y., Gu, Y., Li, M. and Zhang, Z. (2014). Numerical simulation of prepreg resin impregnation effect in vacuum-assisted resin infusion/prepreg co-curing process. *Journal of Reinforced Plastics and Composites*, 0731684414559757.

Ma, X., Yang, Z., Gu, Y., Li, Y., Li, M., Zhang, D., et al. (2014). Manufacture and characterization of carbon fiber composite stiffened skin by resin film infusion/prepreg co-curing process. *Journal of Reinforced Plastics and Composites*, 0731684414543213.

Maia, L. G. and De Oliveira, P. H. I. A. (2005). A review of finite element simulation of aircraft crashworthiness: SAE Technical Paper.

Maimí, P., Camanho, P., Mayugo, J. and Turon, A. (2011). Matrix cracking and delamination in laminated composites. Part II: Evolution of crack density and delamination. *Mechanics of Materials*, 43(4), 194-211.

Maimí, P., Camanho, P. P., Mayugo, J. and Dávila, C. (2007). A continuum damage model for composite laminates: Part I–Constitutive model. *Mechanics of Materials*, 39(10), 897-908.

Majamäki, J. (2002). Impact Simulations of a Composite Helicopter Structure with MSC. Dytran. Proceedings of the 2002 *URL: http://www. mscsoftware. com/events/aero2002/abstracts/pdf/p00701a. pdf) MSC—Worldwide Aerospace Conference & Technology Showcase, Toulouse, France*,

Malik, M., Arif, A., Al-Sulaiman, F. and Khan, Z. (2013). Impact resistance of composite laminate flat plates–A parametric sensitivity analysis approach. *Composite Structures*, 102, 138-147.

Matveev, M., Long, A. and Jones, I. (2014). Modelling of textile composites with fibre strength variability. *Composites Science and Technology*, 105, 44-50.

Matzenmiller, A., Lubliner, J. and Taylor, R. (1995). A constitutive model for anisotropic damage in fiber-composites. *Mechanics of materials*, 20(2), 125-152.

Mayes, J. S. and Hansen, A. C. (2004a). A comparison of multicontinuum theory based failure simulation with experimental results. *Composites Science and Technology*, 64(3), 517-527.

Mayes, J. S. and Hansen, A. C. (2004b). Composite laminate failure analysis using multicontinuum theory. *Composites Science and Technology*, 64(3), 379-394.

Mazhar, F. and Khan, A. M. (2010). Structural Design of a UAV Wing Using Finite Element Method. Proceedings of the 2010 *51st AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference 18th AIAA/ASME/AHS Adaptive Structures Conference 12th*, 3099.

McCartney, L. (2013a). Derivations of energy-based modelling for ply cracking in general symmetric laminates. *Journal of Composite Materials*, 47(20-21), 2641-2673.

McCartney, L. (2013b). Energy methods for modelling damage in laminates. *Journal of Composite Materials*, 47(20-21), 2613-2640.

McKittrick, L. R., Cairns, D. S., Mandell, J., Combs, D. C., Rabern, D. A. and Van Luchene, R. D. (2001). *Analysis of a composite blade design for the aoc 15/50 wind turbine using a finite element model*: Sandia National Laboratories.

Megnis, M., Brondsted, P. and Mikkelsen, L. P. (2004). Damage evolution in laminated composite materials. *Proceedings of Dansk Metalurgisk Selskab*, 33-42.

Mezeix, L., Seman, A., Nasir, M. N. M., Aminanda, Y., Rivai, A., Castanié, B., et al. (2015). Spring-back simulation of unidirectional carbon/epoxy flat laminate composite manufactured through autoclave process. *Composite Structures*, 124, 196-205. doi: http://dx.doi.org/10.1016/j.compstruct.2015.01.005

Michopoulos, J., Badaliance, R., Chwastyk, T., Gause, L. and Mast, P. (1997). Effects of computational technology on composite materials research: the case of the dissipated energy density. Proceedings of the 1997 *Proceedings of the first hellenic conference on composite materials and structures, Greece,* Mises, R. and ANGEW, Z. (1928). Mechanics of plastic deformation in crystals. *Journal of Applied Mathematics and Mechanics*, 8, 161-185.

Mises, R. v. (1928). Mechanik der plastischen Formänderung von Kristallen. *ZAMM-Journal of Applied Mathematics and Mechanics/Zeitschrift für Angewandte Mathematik und Mechanik*, 8(3), 161-185.

Mohammadi, B., Olia, H. and Hosseini-Toudeshky, H. (2015). Intra and damage analysis of laminated composites using coupled continuum damage mechanics with cohesive interface layer. *Composite Structures*, 120, 519-530.

Monroy Aceves, C., Sutcliffe, M. P. F., Ashby, M. F., Skordos, A. A. and Rodríguez Román, C. (2012). Design methodology for composite structures: A small low air-speed wind turbine blade case study. *Materials & Design*, 36, 296-305. doi: http://dx.doi.org/10.1016/j.matdes.2011.11.033

Morka, A., Kwaśniewski, L. and Wekezer, J. W. (2005). Assessment of Passenger Security in Paratransit Buses. *Journal of Public Transportation*, 8(4), 4.

Moure, M., Sanchez-Saez, S., Barbero, E. and Barbero, E. (2014). Analysis of damage localization in composite laminates using a discrete damage model. *Composites Part B: Engineering*.

Murakami, S. (2012). *Continuum Damage Mechanics: A Continuum Mechanics Approach to the Analysis of Damage and Fracture*: Springer Netherlands.

Murakami, S. (2012). *Continuum damage mechanics: a continuum mechanics approach to the analysis of damage and fracture* (Vol. 185): Springer Science & Business Media.

Murugan, S. and Friswell, M. (2013). Morphing wing flexible skins with curvilinear fiber composites. *Composite Structures*, 99, 69-75.

Najafi, A., Huang, D., Rais-Rohani, M., Abdi, F. and Heydari, C. (2010). Simulation of crushing process in composite tubes. Proceedings of the 2010 *51st AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference 18th AIAA/ASME/AHS Adaptive Structures Conference 12th*, 2612.

Nakatani, H., Kosaka, T., Osaka, K. and Sawada, Y. (2011). Damage characterization of titanium/GFRP hybrid laminates subjected to low-velocity impact. *Composites Part A: Applied Science and Manufacturing*, 42(7), 772-781.

Needleman, A. (1987). A continuum model for void nucleation by inclusion debonding. *Journal of applied mechanics*, 54(3), 525-531.

Nimje, S. and Panigrahi, S. (2014). Numerical simulation for stress and failure of functionally graded adhesively bonded tee joint of laminated FRP composite plates. *International Journal of Adhesion and Adhesives*, 48, 139-149.

Ning, H., Janowski, G. M., Vaidya, U. K. and Husman, G. (2007). Thermoplastic sandwich structure design and manufacturing for the body panel of mass transit vehicle. *Composite Structures*, 80(1), 82-91.

Nor, F., Lee, H., Lim, J., Kurniawan, D. and Tamin, M. (2013). Crack Front Profile of Three Point End Notch Flexure Tested Unidirectional CFRP.

Nouri, H., Meraghni, F. and Lory, P. (2009). Fatigue damage model for injection-molded short glass fibre reinforced thermoplastics. *International Journal of Fatigue*, 31(5), 934-942. doi: http://dx.doi.org/10.1016/j.ijfatigue.2008.10.002

O'BRIEN, T. K. and Martin, R. H. (1993). Round robin testing for mode I interlaminar fracture toughness of composite materials. *Journal of composites technology & research*, 15(4), 269-281.

O'Brien, T. K. (1998). Interlaminar fracture toughness: the long and winding road to standardization. *Composites Part B: Engineering*, 29(1), 57-62.

Obradovic, J., Boria, S. and Belingardi, G. (2012). Lightweight design and crash analysis of composite frontal impact energy absorbing structures. *Composite Structures*, 94(2), 423-430.

Ochoa, O. O. and Engblom, J. J. (1987). Analysis of progressive failure in composites. *Composites science and Technology*, 28(2), 87-102.

Ochoa, O. O. and Reddy, J. N. (1992). *Finite element analysis of composite laminates*: Springer.

Orifici, A., Herszberg, I. and Thomson, R. (2008). Review of methodologies for composite material modelling incorporating failure. *Composite Structures*, 86(1), 194-210.

Orifici, A., Shah, S., Herszberg, I., Kotler, A. and Weller, T. (2008). Failure analysis in postbuckled composite T-sections. *Composite Structures*, 86(1), 146-153.

Owen, M. J., Middleton, V. and Jones, I. A. (2000). *Integrated Design and Manufacture Using Fibre-Reinforced Polymeric Composites*: Elsevier Science.

Pandey, R. and GVV, R. K. (2011). Thermal Analysis of Composite Fuselage Skin for Tool Correction.

Park, Y.-B., Nguyen, K.-H., Kweon, J.-H., Choi, J.-H. and Han, J.-S. (2011). Structural analysis of a composite target-drone. *International Journal of Aeronautical and Space Sciences,* 12(1), 84-91.

Phadnis, V. A., Makhdum, F., Roy, A. and Silberschmidt, V. V. (2013). Drilling in carbon/epoxy composites: Experimental investigations and finite element implementation. *Composites Part A: Applied Science and Manufacturing*, 47, 41-51.

Pinho, S., Camanho, P. and De Moura, M. (2004). Numerical simulation of the crushing process of composite materials. *International journal of crashworthiness,* 9(3), 263-276.

Pinho, S., Vyas, G. and Robinson, P. (2013). Response and damage propagation of polymer-matrix fibre-reinforced composites: Predictions for WWFE-III Part A. *Journal of Composite Materials*, 0021998313476972.

Pinho, S. T. (2005). *Modelling failure of laminated composites using physically-based failure models.* Imperial College London (University of London).

Pinho, S. T., Dàvila, C. G., Camanho, P. P., Iannucci, L. and Robinson, P. (2005). Failure models and criteria for FRP under in-plane or three-dimensional stress states including shear non-linearity. *NASA Technical Memorandum,* 213530, 18.

Postec, M., Deletombe, E., Delsart, D. and Coutellier, D. (2008). Study of the influence of the number of inter-ply interfaces on the bearing rupture of riveted composite assemblies. *Composite Structures*, 84(2), 99-113. doi: http://dx.doi.org/10.1016/j.compstruct.2007.06.008

Potluri, P. and Atkinson, J. (2003). Automated manufacture of composites: handling, measurement of properties and lay-up simulations. *Composites Part A: Applied Science and Manufacturing*, 34(6), 493-501. doi: http://dx.doi.org/10.1016/S1359-835X(03)00056-3

Przekop, A., Wu, H. and Shaw, P. (2014). Nonlinear Finite Element Analysis of a Composite Non-Cylindrical Pressurized Aircraft Fuselage Structure. Proceedings of the 2014 *AIAA SciTech Conference*, Puck, A. and Schürmann, H. (1998). Failure analysis of FRP laminates by means of physically based phenomenological models. *Composites Science and Technology*, 58(7), 1045-1067.

Pyo, S. H. and Lee, H. K. (2009). Micromechanics-based elastic-damage analysis of laminated composite structures. *International Journal of Solids and Structures*, 46(17), 3138-3149. doi: http://dx.doi.org/10.1016/j.ijsolstr.2009.04.004

Qiao, P. and Yang, M. (2007). Impact analysis of fiber reinforced polymer honeycomb composite sandwich beams. *Composites Part B: Engineering*, 38(5), 739-750.

Rabotnov, I. (1969). Creep problems in structural members(Soviet book on creep of structural elements at high temperature noting metals, concrete and polymer materials, buckling, variety of structural elements and creep resistance).

Rabotnov, Y. N. (1968). Creep rupture. *In: Hetenyi M, Vincenti M (eds) Proceedings of applied mechanics conference, Stanford University, Springer, Berlin*, 342–349.

Rahmati, S. and Marzbanrad, J. (2011). Impact Resistance and Optimization of Metal-Composite-Metal Auto Body Panel Using Response Surface Methodology (RSM). *International Journal of Advanced Design and Manufacturing Technology*, 3(4), 37-44.

Reeder, J. (1992). An Evaluation of Mixed-Mode Delamination Failure Criteria.

Reeder, J. R. (1993). A bilinear failure criterion for mixed-mode delamination. *ASTM Special Technical Publication*, 1206, 303-303.

Reyes, G. and Kang, H. (2007). Mechanical behavior of lightweight thermoplastic fiber–metal laminates. *Journal of Materials Processing Technology*, 186(1–3), 284-290. doi: http://dx.doi.org/10.1016/j.jmatprotec.2006.12.050

Riccio, A. (2015). *Damage Growth in Aerospace Composites*: Springer International Publishing.

Riccio, A., De Luca, A., Di Felice, G. and Caputo, F. (2014). Modelling the simulation of impact induced damage onset and evolution in composites. *Composites Part B: Engineering*, 66, 340-347.

Riccio, A., Raimondo, A., Di Felice, G. and Scaramuzzino, F. (2014). A numerical procedure for the simulation of skin–stringer debonding growth in stiffened composite panels. *Aerospace Science and Technology*, 39, 307-314.

Rice, J. R. (1968). A path independent integral and the approximate analysis of strain concentration by notches and cracks. *Journal of applied mechanics*, 35(2), 379-386.

Romhany, G. and Szebenyi, G. (2009). Interlaminar crack propagation in MWCNT/fiber reinforced hybrid composites. *Express Polymer Letters*, 3(3), 145-151.

Romilly, D. and Clark, R. (2008). Elastic analysis of hybrid bonded joints and bonded composite repairs. *Composite Structures*, 82(4), 563-576.

Rosen, B. W. (1964). Tensile failure of fibrous composites. *AIAA journal*, 2(11), 1985-1991.

Rossi, M. and Muller de Almeida, S. (2009). Design and Analysis of a Composite Fuselage. *Instituto Tecnológico de Aeronáutica*.

Rostam-Abadi, F., Chen, C.-M. and Kikuchi, N. (2000). Design analysis of composite laminate structures for light-weight armored vehicle by homogenization method. *Computers & Structures*, 76(1), 319-335.

Saeed, M. U., Chen, Z., Chen, Z. and Li, B. (2014). Compression behavior of laminated composites subjected to damage induced by low velocity impact and drilling. *Composites Part B: Engineering*, 56, 815-820. doi: http://dx.doi.org/10.1016/j.compositesb.2013.09.017

Saeedi, N., Sab, K. and Caron, J.-F. (2013). Cylindrical bending of multilayered plates with multi-delamination via a layerwise stress approach. *Composite Structures*, 95, 728-739.

Sandhu, R. (1974). Ultimate Strength Analysis of Symmetric Laminates: DTIC Document.

Sapozhnikov, S. B. and Cheremnykh, S. I. (2013). The strength of fibre reinforced polymer under a complex loading. *Journal of Composite Materials*, 0021998313476328.

Satapathy, M. R., Vinayak, B., Jayaprakash, K. and Naik, N. (2013). Fatigue behavior of laminated composites with a circular hole under in-plane multiaxial loading. *Materials & Design*, 51, 347-356.

Schuecker, C. and Pettermann, H. (2008). Fiber reinforced laminates: progressive damage modeling based on failure mechanisms. *Archives of Computational Methods in Engineering*, 15(2), 163-184.

Schuecker, C. and Pettermann, H. (2013). A constitutive ply model predicting stiffness degradation as well as inelastic strain accumulation and its application to WWFE-III (Part A). *J Compos Mater*, 47(20-21), 2575-2593.

Selmy, A. I., Elsesi, A. R., Azab, N. A. and Abd El-baky, M. A. (2011). Monotonic properties of unidirectional glass fiber (U)/random glass fiber (R)/epoxy hybrid composites. *Materials & Design*, 32(2), 743-749. doi: http://dx.doi.org/10.1016/j.matdes.2010.07.031

Seresta, O., Gürdal, Z., Adams, D. B. and Watson, L. T. (2007). Optimal design of composite wing structures with blended laminates. *Composites Part B: Engineering*, 38(4), 469-480.

Sethi, S., Rathore, D. K. and Ray, B. C. (2015). Effects of temperature and loading speed on interface-dominated strength in fibre/polymer composites: An evaluation for in-situ environment. *Materials & Design*, 65, 617-626.

Shahid, I. and Chang, F.-K. (1995). An accumulative damage model for tensile and shear failures of laminated composite plates. *Journal of Composite Materials*, 29(7), 926-981.

Shang, Y.-B. and Shi, H.-J. (2014). Micromechanical analysis of stochastic fiber/matrix interface strength effect on transverse tensile property of fiber reinforced composites. *Journal of Reinforced Plastics and Composites*, 0731684414565435.

Shi, Y., Pinna, C. and Soutis, C. (2014). Modelling impact damage in composite laminates: A simulation of intra-and inter-laminar cracking. *Composite Structures*, 114, 10-19.

Shi, Y., Swait, T. and Soutis, C. (2012). Modelling damage evolution in composite laminates subjected to low velocity impact. *Composite Structures*, 94(9), 2902-2913.

Shin, D., Kim, H. and Lee, J. (2014). Numerical analysis of the damage behavior of an aluminum/CFRP hybrid beam under three point bending. *Composites Part B: Engineering*, 56, 397-407.

Sicot, O., Rousseau, J. and Hearn, D. (2007). INFLUENCE OF STACKING SEQUENCES ON IMPACT DAMAGE OF PRE-STRESSED ISOTROPIC COMPOSITE LAMINATES. *Paper presented at the 16th Int. Conf. on Composite Materials*, Kyoto, Japan.

Simon, J.-W., Höwer, D., Stier, B. and Reese, S. (2014). Meso-mechanically motivated modeling of layered fiber reinforced composites accounting for delamination. *Composite Structures*.

Simons, G. (2014). *The Airbus A380: A History*: Pen & Sword Books.

Singh, C. V. and Talreja, R. (2013). A synergistic damage mechanics approach to mechanical response of composite laminates with ply cracks. *Journal of Composite Materials*, 47(20-21), 2475-2501.

Siromani, D. (2013). *Crashworthy Design and Analysis of Aircraft Structures*: DREXEL UNIVERSITY.

Sisodia, R. P. S., Waghmare, N. K. and Dixit, A. (2010). An experimental and numerical crashworthiness study of composite tubes. Proceedings of the 2010 *ASME early career technical conference, October*, 1-2.

Smith, P. (2001). Carbon fiber reinforced plastics-properties. *Comprehensive composite materials*, 2, 107-150.

Soni, G., Gupta, S., Singh, R., Mitra, M., Yan, W. and Falzon, B. G. (2014). Study of localized damage in composite laminates using micro–macro approach. *Composite Structures*, 113, 1-11.

Stark, W., Jaunich, M. and McHugh, J. (2015). Dynamic Mechanical Analysis (DMA) of epoxy carbon-fibre prepregs partially cured in a discontinued autoclave analogue process. *Polymer Testing*, 41, 140-148. doi: http://dx.doi.org/10.1016/j.polymertesting.2014.11.004

Steven Mayes, A. C. H., J. (2001). Multicontinuum failure analysis of composite structural laminates. *Mechanics of Composite Materials and Structures*, 8(4), 249-262.

Su, Z., Tay, T., Ridha, M. and Chen, B. (2014). Progressive damage modeling of open-hole composite laminates under compression. *Composite Structures*.

Sue, H.-J., Jones, R. and Garcia-Meitin, E. (1993). Fracture behaviour of model toughened composites under mode I and mode II delaminations. *Journal of materials science*, 28(23), 6381-6391.

SZEKRÉNYES, A. (2002). Overview on the experimental investigations of the fracture toughness in composite materials. *Hungarian Electronic Journal of Sciences, http://hej. sze. hu/, Mechanical Engineering Section, MET-020507-A.*

Szekrényes, A. (2013). Interface fracture in orthotropic composite plates using second-order shear deformation theory. *International Journal of Damage Mechanics*, 1056789513478957.

Tabor, D. (1978). Properties of Matter: Penguin Books, London, UK.

Tagarielli, V. L., Minisgallo, G., McMillan, A. J. and Petrinic, N. (2010). The response of a multi-directional composite laminate to through-thickness loading. *Composites Science and Technology*, 70(13), 1950-1957. doi: http://dx.doi.org/10.1016/j.compscitech.2010.07.013

Taketa, I., Okabe, T. and Kitano, A. (2008). A new compression-molding approach using unidirectionally arrayed chopped strands. *Composites Part A: Applied Science and Manufacturing*, 39(12), 1884-1890. doi: http://dx.doi.org/10.1016/j.compositesa.2008.09.012

Talreja, R. (1985). Transverse cracking and stiffness reduction in composite laminates. *Journal of composite materials*, 19(4), 355-375.

Talreja, R. (1994). *Damage mechanics of composite materials*: Elsevier.

Talreja, R. (2014). Multiscale Modeling of Damage in Composite Materials *Multiscale Modeling of Complex Materials* (pp. 179-209): Springer.

Talreja, R. and Singh, C. V. (2012). *Damage and Failure of Composite Materials*: Cambridge University Press.

Tamin, M. N. and Shaffiar, N. M. (2014). *Solder Joint Reliability Assessment: Finite Element Simulation Methodology*: Springer.

Tanaka, K., Kageyama, K. and Hojo, M. (1995). Prestandardization study on mode II interlaminar fracture toughness test for CFRP in Japan. *Composites*, 26(4), 257-267.

Tay, T., Sun, X. and Tan, V. (2014). Recent efforts toward modeling interactions of matrix cracks and delaminations: an integrated XFEM-CE approach. *Advanced Composite Materials*, (ahead-of-print), 1-18.

Taylor, R. P. (2008). Fibre composite aircraft – capability and safety: Australian Transport Safety Bureau.

Theocaris, P. S. (1992). Weighing failure tensor polynomial criteria for composites. *International Journal of Damage Mechanics*, 1(1), 4-46.

Timoshenko, S. P. and Woinowsky-Krieger, S. (1989). *Theory of Plates and Shells*: McGraw-Hill.

Tomaszewski, H., Węglarz, H., Wajler, A., Boniecki, M. and Kalinski, D. (2007). Multilayer ceramic composites with high failure resistance. *Journal of the European Ceramic Society*, 27(2–3), 1373-1377. doi: http://dx.doi.org/10.1016/j.jeurceramsoc.2006.04.030

Tong, L. (1997). An assessment of failure criteria to predict the strength of adhesively bonded composite double lap joints. *Journal of Reinforced Plastics and Composites*, 16(8), 698-713.

Tsai, S. W. (1964). Structural Behavior of Composite Materials: DTIC Document.

Tsai, S. W. (1965). Strength Characteristics of Composite Materials: DTIC Document.

Tsai, S. W. and Wu, E. M. (1971). A general theory of strength for anisotropic materials. *Journal of composite materials*, 5(1), 58-80.

Turan, K. (2013). Joint angle effect on the failure behavior of pinned joint composite plates. *Journal of Composite Materials*, 47(24), 3027-3039.

Turon, A., Camanho, P. P., Costa, J. and Dávila, C. G. (2004). An interface damage model for the simulation of delamination under variable-mode ratio in composite materials.

Ubaid, J., Kashfuddoja, M. and Ramji, M. (2014). Strength prediction and progressive failure analysis of carbon fiber reinforced polymer laminate with multiple interacting holes involving three dimensional finite element analysis and digital image correlation. *International Journal of Damage Mechanics*, 23(5), 609-635.

Ueda, T., Hasan, M., Nagai, K. and Sato, Y. (2004). Stress-strain relationship of concrete damaged by freezing and thawing cycles. Proceedings of the 2004 *Proceedings of FraMCoS*, 645-652.

Ullah, H., Harland, A. R., Lucas, T., Price, D. and Silberschmidt, V. V. (2012). Finite-element modelling of bending of CFRP laminates: Multiple delaminations. *Computational Materials Science*, 52(1), 147-156.

Ungsuwarungsri, T. and Knauss, W. G. (1987). The role of damage-softened material behavior in the fracture of composites and adhesives. *International Journal of Fracture*, 35(3), 221-241.

Uyar, I., Gozluklu, B. and Coker, D. (2014). Dynamic delamination in curved composite laminates under quasi-static loading. Proceedings of the 2014 *Journal of Physics: Conference Series*, 012042.

Van, X. Q., Du, S. Y. and Duo, W. (1991). An engineering method of determining the delamination fracture toughness of composite laminates. *Engineering fracture mechanics*, 39(4), 623-627.

Varna, J. (2013). Modelling mechanical performance of damaged laminates. *Journal of Composite Materials*, 47(20-21), 2443-2474.

Veedu, V. P., Cao, A., Li, X., Ma, K., Soldano, C., Kar, S., et al. (2006). Multifunctional composites using reinforced laminae with carbon-nanotube forests. *Nature materials*, 5(6), 457-462.

Vlahopoulos, N., Schiller, N. and Lee, S. (2011). Energy finite element analysis developments for vibration analysis of composite aircraft structures. *Energy*, 11, 0193.

Voyiadjis, G. Z. (2012). *Advances in Damage Mechanics: Metals and Metal Matrix Composites: Metals and Metal Matrix Composites*: Elsevier.

Wagner, M. and Norris, G. (2009). *Boeing 787 Dreamliner*: MBI Publishing Company.

Wakeman, M. D., Rudd, C. D., Cain, T. A., Brooks, R. and Long, A. C. (2000). Compression moulding of glass and polypropylene composites for optimised macro- and micro-mechanical properties. 4: Technology demonstrator — a door cassette structure. *Composites Science and Technology*, 60(10), 1901-1918. doi: http://dx.doi.org/10.1016/S0266-3538(00)00066-X

Walbran, W. A., Bickerton, S. and Kelly, P. A. (2009). Measurements of normal stress distributions experienced by rigid liquid composite moulding tools. *Composites Part A: Applied Science and Manufacturing*, 40(8), 1119-1133. doi: http://dx.doi.org/10.1016/j.compositesa.2009.05.004

Wang, F., Li, L., Chen, Z. and Zeng, X. (2012). Statistical modeling for the accumulation of transverse matrix cracking in cross-ply laminates. *Polymer Composites*, 33(6), 912-917.

Warren, C. D. (2012). High Volume Vehicle Materials *US Low Carbon Vehicles Workshop*: Georgia Technological University, Atlanta, Georgia.

Wei, X., Tran, P., de Vaucorbeil, A., Ramaswamy, R. B., Latourte, F. and Espinosa, H. D. (2013). Three-dimensional numerical modeling of composite panels subjected to underwater blast. *Journal of the Mechanics and Physics of Solids*, 61(6), 1319-1336.

Weißgraeber, P., Stein, N. and Becker, W. (2014). A general sandwich-type model for adhesive joints with composite adherends. *International Journal of Adhesion and Adhesives*, 55, 56-63.

Whitcomb, J. D. (1984). *Analysis of instability-related growth of a through-width delamination* (Vol. 86301): National Aeronautics and Space Administration, Langley Research Center.

White, S. R. (1987). *Mixed-mode interlaminar fracture of graphite/epoxy composites*.

Wilson, M. J. (2003). Finite element analysis of glass fibre reinforced thermoplastic composites for structural automotive components. *Assessment*, 2, 22.

Wisnom, M., Hill, G. and Jones, M. (2001). Through thickness failure prediction of composite structural elements. Proceedings of the 2001 *Proceedings of the 13th international conference on composite materials, Beijing, China. Paper*,

Wu, E. M. and Reuter Jr, R. (1965). Crack extension in fiberglass reinforced plastics: DTIC Document.

Yamada, S. and Sun, C. (1978). Analysis of laminate strength and its distribution. *Journal of Composite Materials*, 12(3), 275-284.

Yamaguchi, T., Okabe, T. and Yashiro, S. (2009). Fatigue simulation for titanium/CFRP hybrid laminates using cohesive elements. *Composites Science and Technology*, 69(11), 1968-1973.

Yashiro, S., Okabe, T. and Takeda, N. (2007). Damage identification in a holed CFRP laminate using a chirped fiber Bragg grating sensor. *Composites science and technology*, 67(2), 286-295.

Ye, L. (1988). Role of matrix resin in delamination onset and growth in composite laminates. *Composites science and technology*, 33(4), 257-277.

Ye, L., Feng, P. and Yue, Q. (2012). *Advances in FRP Composites in Civil Engineering: Proceedings of the 5th International Conference on FRP Composites in Civil Engineering (CICE 2010), Sep 27-29, 2010, Beijing, China*: Springer Berlin Heidelberg.

Yenilmez, B., Senan, M. and Murat Sozer, E. (2009). Variation of part thickness and compaction pressure in vacuum infusion process. *Composites Science and Technology*, 69(11–12), 1710-1719. doi: http://dx.doi.org/10.1016/j.compscitech.2008.05.009

Yuexin, D., Zhaoyuan, T., Yan, Z. and Jing, S. (2008). Compression Responses of Preform in Vacuum Infusion Process. *Chinese Journal of Aeronautics*, 21(4), 370-377. doi: http://dx.doi.org/10.1016/S1000-9361(08)60048-5

Zechner, J. and Kolednik, O. (2013). Fracture resistance of aluminum multilayer composites. *Engineering Fracture Mechanics*, 110, 489-500. doi: http://dx.doi.org/10.1016/j.engfracmech.2012.11.007

Zhang, J., Chaisombat, K., He, S. and Wang, C. H. (2012). Hybrid composite laminates reinforced with glass/carbon woven fabrics for lightweight load bearing structures. *Materials & Design*, 36, 75-80. doi: http://dx.doi.org/10.1016/j.matdes.2011.11.006

Zhang, J., Liu, F., Zhao, L., Chen, Y. and Fei, B. (2014). A progressive damage analysis based characteristic length method for multi-bolt composite joints. *Composite Structures*, 108, 915-923.

Zhang, K., Gu, Y., li, M. and Zhang, Z. (2014). Effect of rapid curing process on the properties of carbon fiber/epoxy composite fabricated using vacuum assisted resin infusion molding. *Materials & Design*, 54, 624-631. doi: http://dx.doi.org/10.1016/j.matdes.2013.08.065

Zhang, X. (1998). Impact damage in composite aircraft structures-experimental testing and numerical simulation. *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, 212(4), 245-259.

Zhao, G. P. and Cho, C. D. (2007). Damage initiation and propagation in composite shells subjected to impact. *Composite Structures*, 78(1), 91-100. doi: http://dx.doi.org/10.1016/j.compstruct.2005.08.013

Zhao, L., Qin, T., Chen, Y. and Zhang, J. (2014). Three-dimensional progressive damage models for cohesively bonded composite π joint. *Journal of Composite Materials*, 48(6), 707-721.

Zhou, S., Wang, Z., Zhou, J. and Wu, X. (2013). Experimental and numerical investigation on bolted composite joint made by vacuum assisted resin injection. *Composites Part B: Engineering*, 45(1), 1620-1628.

Zhu, J., Imam, A., Crane, R., Lozano, K., Khabashesku, V. N. and Barrera, E. V. (2007). Processing a glass fiber reinforced vinyl ester composite with nanotube enhancement of interlaminar shear strength. *Composites Science* *and Technology*, 67(7–8), 1509-1517. doi: http://dx.doi.org/10.1016/j.compscitech.2006.07.018

Zubillaga, L., Turon, A., Renart, J., Costa, J. and Linde, P. (2015). An experimental study on matrix crack induced delamination in composite laminates. *Composite Structures*, 127, 10-17. doi: http://dx.doi.org/10.1016/j.compstruct.2015.02.077