UNIVERSITI PUTRA MALAYSIA

ANALYSIS OF FIBRE METAL LAMINATE BASED ON CARBON FIBRE HYBRID COMPOSITES FOR AERO-ENGINE APPLICATIONS

IBRAHIM MOHAMMED

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By

IBRAHIM MOHAMMED

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

May 2018

DEDICATION

Dedicated to
My late father
Alhaji Muhammad Atiku Yantumaki
My mother, wife, children
And to my Brothers and Sisters, for their support, encouragement, and prayers

Thank You

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman : Associate Professor. Ir. Ts. Abd Rahim Abu Talib, P.Eng P.Tech
Faculty : Engineering

Due to the problems of flammability, weight and health risk associated with the materials in fire designated zone of an aircraft engine, there is a need to develop new composites that will resolve the fire issues. Accordingly, two classes of composites, the fibre metal laminates and the aluminium alloy coated with silica aerogel composites are examined in this research. The fibre metal laminate composites use synthetic fibre (carbon) and natural fibres (kenaf and flax) were tested with metal alloy. The study present a novelty in hybridising the synthetic and natural fibre and also using an aerogel to coat the aluminium alloy in fire designated zone of an aircraft engine. In order to ensure the validity of such composites, the fire resistance, mechanical, thermal, and impact velocity properties of the composites were experimentally investigated in this research. The main aim of the study is to investigate the load/fire operational performance of the fabricated composites for the fire designated zone of an aircraft engine at some high-temperature for future use in aerospace industries. The composites' different layers, stacking sequence, and materials with the same thickness were fabricated in a mould using the hand lay-up method, compressed with a compression machine, cured within 24 hours at room temperature and post-cured for three hours in an oven at 80^{o}C. The burn-through fire test was carried out using a propane-air burner conforming to the ISO2685 standard. The mechanical test carried out on the composite was based on the ASTM standard of the properties that involves the use of a 100 kN load cell of Universal Testing Machine (UTM). A gun tunnel system placed 14 inches away from the target was used for the impact velocity test, followed by a thermogravimetric analysis (TGA) and a dynamic mechanical analysis (DMA) as the thermal test. The results obtained indicate that the composites have high values of all properties as compared with the existing literature as in glass reinforced aluminium laminate with a tensile modulus of about 3.7 GPa, a compressive modulus of 0.56 GPa and a flexural modulus of 0.5

GPa. The TGA thermal test shows 58.85% as the highest residue percentage of the composite under test and an increase of storage modulus in the DMA result. Impact-wise, the composites show a remarkable improvement with high impact strength and absorb energy with highest values of 9.25 kJ/m^2 and 81.02 J respectively. In the fire test, the composites can withstand high flame temperature and heat flux according to the ISO2685 standard. The results of all the tests show a remarkable improvement in all the properties with almost 10-14% of fire behaviour, mechanical, and thermal as compared with glass reinforced aluminium laminate (GLARE) of the various fibre metal laminates and aluminium alloy composites coated with different types of silica aerogel. Conclusively, the study revealed that both composites have excellent mechanical, thermal, impact velocity and fire resistance properties that can be applied as components in the fire designated zone of an aircraft engine.

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

ANALISIS LAMINAT LOGAM SERAT BERDASARKAN KOMPOSIT HYBRID SERAT KARBON UNTUK APLIKASI AERO-ENJIN

Oleh

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Pengerusi : Profesor Madya Ir. Ts. Abd Rahim Abu Talib, P.Eng, P.Tech
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Oleh kerana masalah mudah terbakar, berat dan risiko kesihatan yang berkaitan dengan bahan-bahan di zonyang ditetapkansebagaizonkebakaranenjinpesawat, ada keperluan untuk membangunkan komposit baru yang akan menyelesaikan isu kebakaran. Sehubungan itu, dua kelas komposit, laminat logam serat dan aloi aluminium yang disalut dengan komposit aerogel silika diperiksa dalam kajian ini. Komposit laminat serat logam yang menggunakan gentian sintetik (karbon) dan gentian semulajadi (kenaf dan flax) diuji dengan aloi logam. Kajian ini memperlihatkan pembahanian dalam meiggabunguan serat sintetik dan semulajadi dan juga menggunakan aerogel untuk melapisi aloi aluminium dalam zon yang ditetapkan sebagai zon enjin pesawat. Untuk memastikan kesahihan komposit sedemikian, rintangan kebakaran, mekanikal, terma, dan sifat-sifat halaju impak komposit telah dikaji secara eksperimen dalam kajian ini. Tujuan utama kajian ini adalah untuk mengkaji beban / prestasi operasi kebakaran komposit yang difabrikasi untuk zon yang ditetapkan sebagai zon kebakaran enjin pesawat pada beberapa suhu tinggi untuk penggunaan masa hadapan dalam industri aeroangkasa. Lapisan berlainan komposit, cara penyusunan, dan bahan dengan ketebalan yang sama dibuat di acuan dengan menggunakan kaedah pemasangan tangan, dimampatkan dengan mesin mampatan, pulih dalam masa 24 jam pada suhu bilik dan seterusnya melalui proses selepas sembuh selama tiga jam dalam ketuhar pada 80ºC. Ujian bakar tembus kebakaran dilakukan menggunakan pembakar propana-udara yang sesuai dengan piawaian ISO2685. Ujian mekanikal yang dijalankan ke atas komposit adalah berdasarkan kepada standard ASTM komposit tersebut yang melibatkan penggunaan sel beban seberat 100 kN Universal Testing Machine (UTM).Sistem terowong senapang diletakkan 14 inci dari sasaran digunakan untuk ujian halaju impak, diikuti oleh analisis termogravimetrik (TGA) dan analisis mekanikal dinamik (DMA) sebagai ujian haba. Keputusan yang diperoleh menunjukkan bahawa komposit mempunyai nilai tinggi bagi semua sifat berbanding dengan kajian yang

sedia ada seperti laminat aluminium bertetulang kaca dengan modulus tegangan kira-kira 3.7 GPa, modulus mampatan sebanyak 0.56 GPa dan modulus lenturan bernilai 0.5 GPa. Ujian termal TGA menunjukkan 58.85% sebagai peratusan residu tertinggi komposit di bawah ujian dan peningkatan modulus penyimpanan dalam keputusan DMA. Dari sudut impak, komposit menunjukkan peningkatan yang luar biasa dengan kekuatan impak yang tinggi dan menyerap tenaga dengan nilai tertinggi 9.25 kJ / m^2 dan 81.02 J masing-masing. Dalam ujian kebakaran, komposit boleh menahan suhu api tinggi dan fluks haba mengikut piawaian ISO2685. Keputusan semua ujian menunjukkan peningkatan yang luar biasa dalam semua sifat dengan hampir 10-14% kebakaran, mekanikal, dan haba berbanding dengan laminat aluminium bertetulang kaca (GLARE) dari pelbagai laminates logam serat dan komposit aloi aluminium yang disalut dengan pelbagai jenis silika aerogel. Secara keseluruhannya, kajian menunjukkan bahawa kedua-dua komposit mempunyai sifat mekanikal, haba, halaju impak dan ciri-ciri ketahanan api yang sangat baik yang boleh digunakan sebagai komponen dalam zon yang ditetapkan sebagai zon kebakaran enjin pesawat.

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

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P	Density (g/cm^3)
M	Poisson's ratio
D	Maximum deflection of the centre of the beam (mm)
L	Length (mm)
H	Height (mm)
B	Width (mm)
I	Distance Between Two Supports (mm)
Ω	Maximum load (N)
Δ	Flexural Strength (MPa)
K	Thermal Conductivity (W/mK)
ΔT	Temperature Difference (^oC)
D	Thickness (mm)
W	Heat flow (W)
Σ	Stefan's Boltzmann constant (W/ (m^2·K^4)
$\mathcal{E}_s$	Emissivity
α_s,	Surface Absorptivity
q_{inc}	Incident Radiation (W/m^2)
q_{rad}	Net Heat Absorbed by Radiation (J/sm^{o}C)
T_∞	Gas Temperature (^{o}C)
T_s	Surface Temperature (^{o}C)
A	Surface Area (m^2)
H	Heat Transfer Coefficient(kW/m^{2}K)

q_{conv}	Convective Heat Transfer (W/m^2K)
V_r	Residual Velocity (m/s)
V_i	Initial Velocity (m/s)
V_b	Ballistic Limit Velocity (m/s)
P.E	Potential Energy (J)
K.E	Kinetic Energy (J)
È	Young's Modulus (MPa)
$\mathcal{E}_f$	Flexural strain (%)
$\mathcal{E}$	Strain (%)
$б_f$	Flexural Stress (MPa)
Δ	Stress (MPa)
U	Voltage Output (V)
S	Sensitivity V/ (W/m^2)
Φ	Heat Flux (kW/m^2)
E_{Abs}	Energy Absorption (J)
m_p	Mass of projectile (g)
T_g	Transition Glass Temperature (^oC)

LIST OF ABBREVIATIONS

AA	Aluminium Alloy
CAFRALL	Carbon Fibre Flax Reinforced Aluminium Laminates
CAKRALL	Carbon Fibre Kenaf Reinforced Aluminium Laminates
CARALL	Carbon Fibre Reinforced Aluminium Laminates
CF+AA	Carbon Fibre Reinforced Aluminium Laminates with Aluminium Alloy at Top and Bottom
GLARE	Glass Fibre Reinforced Aluminium Laminates
ARALL	Aramid Reinforced Aluminium Laminates
CFRP	Carbon Fibre Reinforced Polymer
FMLs	Fibre-Metal Laminates
CMCs	Ceramic Matrix Composites
MMCs	Metal Matrix Composites
PMCs	Polymer Matrix Composites
FF	Flax Fibre
KF	Kenaf Fibre
CF	Carbon Fibre
ASTM	American Society for Testing and Materials
SBG	Schmidt Boelter Gauge
QI	Impact energy
HCP	Hexagonal Close Packed
GEA	Green Earth Aerogel
Enova	Enova® IC3100
ISO	International Organisation for Standardisation

Fps	Frame per Second
Ppi	Pixel per Image
PP	Polypropylene
PEEK	Poly-ether-ether-ketone
PPS	Polyphenylene Sulphide
PVC	Polyvinyl Chloride
FAA	Federal Aviation Administration
CASA	Civil Aviation Safety Authority
NASA	National Aeronautics and Space Administration

CHAPTER 1

INTRODUCTION

1.1 Background

Safety is the state of being protected from any threat that may cause injury, risk of life, or any form of danger. It is also a form of safeguard against any type of significant collapse of materials and components in any system, any error that might lead to accidents and trauma, or any other circumstances that can be considered undesirable. There are different types of safety that includes safety on fire, chemicals, water pollution among others.

Fire safety is a quantifier that protects the uncontrolled fire from igniting and is used to terminate the growth and consequences of a fire after it starts. Fuel, air and ignition source are the prerequisites that can cause a fire. In an aircraft, there are plenty of hot materials that can easily ignite, most of which are covered by cowling in case of fire outbreak in the engine. Most of the fires that occur in the cowl are due to the type of materials used in the cowl, age, fatigue and improper maintenance. Another fire source in an aerospace engine is the electrical power from alternators, generators, and batteries. Most of the aerospace fires comprise four types which are fires during engine start, electrical fires, in-flight engine fires, and post-crash fires.

The longer hours of flight requires a conducive environment and a better level of assurance in safety and well-being of passengers and their belongings, as well as the aircraft crew. The higher amount of fibrous materials used increases the level of safety and the required results in constructing the aerospace parts. The prime root of fire accident in aircraft is flammability, which maybe fended off by the use of flame-retardant fibrous materials.

Aircraft structures are designed and constructed to resist different loading scenarios during their operational life. For fire safety reason, the Federal Aviation Administration (FAA) has instituted a set of prerequisites to safeguard the critical parts and components in aircraft and engine installation that is capable to perform effectively and allow safe engine shutdown if affected by the fire. The definition of an incident includes an occurrence other than an accident, associated with the operation of an aircraft, which affects or could affect the safe operation of an aircraft. The incidents are caused by many factors such as engine failure, pilot error, and bad weather as well as mechanical and avionic faults. The design and fabrication of the engine components in the propulsion system and the materials used in fire designated zone must minimise the tendency of the occurrence and spread of fire as stated in the Advisory (2002).

Therefore, the propulsion system is the heart of any aircraft. Decades ago, aeronautical engineers had contended to rapidly build and do continuous research on how to create better, lighter, and more powerful components for fire designated zone of an aircraft engines. However, even with the tremendous development of the gas turbines nowadays, engines' fire safety is an issue that the aerospace industry is still facing. The modern aircraft engines nowadays use highly flammable fuel, and also requires hydraulic fluid and lubricating oil to operate. The support components and flammable tanks in fire designated zone must be fireproof materials. Components carrying flammable fluid in an area subjected to engine fire conditions, components which convey flammable fluid in a fire designated zone, fittings and lines in fire designated zone must be made from fire-resistant materials, for the components to be shielded against the ignition of any leaking flammable fluid. Any leaking within the potential fire zone in the small turbofan engine of Figure 1.1 must be safeguarded to avoid fire (Rolls-Royce, 1996).

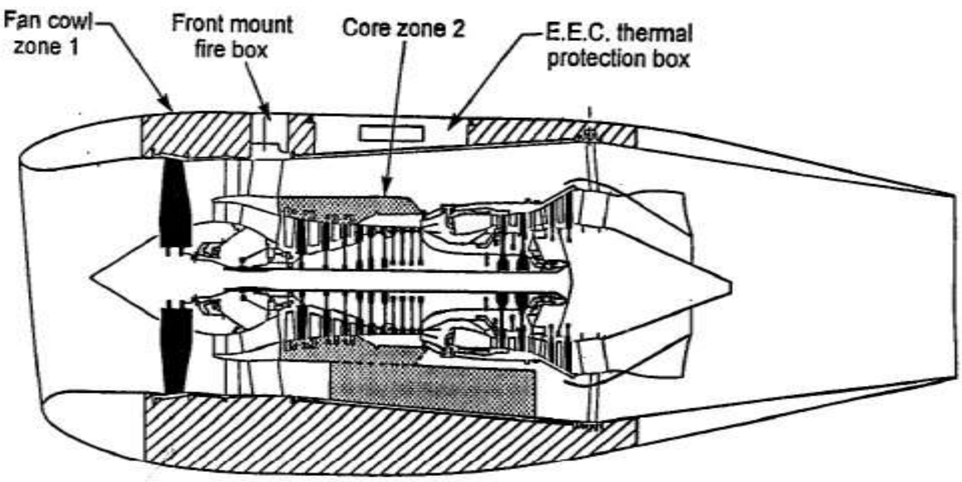

Figure 1.1 : Fire Zones in a Small Turbofan BR710 Power Plant (Abu Talib, 2003)

The research conducted had focused on fire test using ISO2685 propane-air burner on fire flame characterisation, temperature and heat flux density calibration of the burner, and had also studied mechanical and thermal properties with fire resistance for fire designated zone of an aircraft engine components using different fibre metal laminates (FMLs) composite of aluminium alloy 2024-T3 with synthetic (woven carbon fibre) and natural fibres (flax and kenaf) using an epoxy resin/hardener (HL002 TA/B) as polymer. The fire resistance properties of aluminium alloy 2024-T3 coated with three types of silica aerogel (Hamzel®, Enova® IC3100 and GEA™ 0.125) were also studied.

The fire testing incorporates exposure of components in fire designated zone of an aircraft to a standard flame. A standard flame has been described by International Standard ISO2685 (1992) as the flame having the characteristics temperature of 1100 ± 80ºC, and a heat flux density received by the standard apparatus of 116 ± 10 kW/m2. The component is regarded to be airworthy if it has the power to continue to perform for its design purposes after flame strike from a standard ISO2685 propane-air burner for the given time needed. The standard fire-test procedure comprises the exposure of the engine components in designated fire zones to a standard flame. The composites considered in this study are deemed to be airworthy since it performed its design function after flame strike from a standard burner for the given time (5 minutes for fire resistant and a further 10 minutes for fireproof). The following are the description of some terms used in this research.

Fireproof Materials: is defined as materials with the ability to withstand a heat from a severe fire for an extended duration of 15 minutes of flame exposure. The fireproof materials used in this study meet the requirement after withstanding the stated time. Flammable fluid tank and supports components of fire designated zone of an aircraft must be made from fireproof materials. The fireproof materials of this study withstand a severe fire flame temperature of 1100 ± 80ºC and a heat flux of 116 ± 10 kW/m2 using a propane-air burner according to ISO2685 standard (ISO2685, 1998).

Fire-Resistant Materials: is defined as materials with the ability to withstand a heat from a severe fire for an extended duration of 5 minutes of flame exposure. It is the capacity to perform the intended functions under the heat and other conditions that are likely to occur when there is a fire at the place concerned. Aircraft components carrying flammable fluid in an area subjected to engine fire conditions, components which convey flammable fluid in a fire designated zone, fittings and lines in fire designated zone must be made from fire-resistant materials.

1.2 Fire Designated Zone of an Aircraft

The fire designated zone of modern aircraft must be protected by a fixed protection system due to the fire dangerous threats to the zone. The zone is a region that is designed to require fire detection and a high degree of high temperature fire resistance materials and composites. The zones need to have fire detection and extinguishing equipments in case of fire. Among the zones on aircraft that have a fixed fire detection and fire extinguisher system are: engines and auxiliary power unit (APU), cargo and baggage compartments, lavatories on transport aircraft, electronic bays, wheel wells and a bleed air ducts (Quintiere, 2006).

The main concerned of this research is the fire designated zone of an aircraft engine, which is defined as a region of the aircraft, such as engine and auxiliary power unit compartments designated to require fire detection/protection and fire extinguishing equipment, and also needs to be shielded by either fireproof or fire-resistant material. The fire zones of an aircraft engine includes: the engine power section of reciprocating engines, the engine accessory section of reciprocating engines, complete power-plant compartment in which there is no isolation between the engine power section and the engine accessory section, for reciprocating engines, auxiliary power unit compartment, fuel-burning heater and other combustion equipment installation, compressor and accessory sections of turbine engines, and combustor, turbine, and tailpipe sections of turbine engine installations except sections that do not contain lines and components carrying flammable fluids or gases and are isolated from the designated fire zone.

Titanium alloy and titanium aluminides were among the main materials used in fire designated zones of an aircraft engine due to strength/weight ratio of it. The materials has the properties to be used in the zone, but with some limitations such as the material composition and the effect of processing and properties of its microstructure with lower temperature resistance (Antolovich et al., 2016; Bewlay et al., 2016; Clemens & Kestler, 2000; Rugg et al., 2014). Glass fibre reinforced aluminium laminates was used in fabricating a composite component by Sikoutris (2012) using 4mm thickness of the composites, the composite shows less tensile strength and higher weight as compared with the fabricated composites in the present study. Also, the study of the CFRP shows that the fatigue crack growth in the composite was increasing as the crack was initiated during the test (Sikoutris, 2012).

A glass reinforced aluminium laminate (GLARE) was fabricated by Sikoutris (2012) as component of an aircraft used at high temperature. The fabricated composite sandwich five sheets of 0.4 mm aluminium alloy 2024-T3 and four sheets of 0.25 mm carbon fibre with a mass of 467g and a thickness of 4 mm, the composite was laid unidirectional. The composite undergoes fire test, mechanical and thermal test; whereby it withstand a high temperature application for 15 minutes according to ISO2685 standard, with moderate mechanical properties. The composite was used as the benchmark of this study.

The current study uses experimental approach for the novel hybrid composite of FML that consists of aluminium alloy 2024-T3, carbon fibre, kenaf and flax; the other composite consists of aluminium alloy coated with three types of silica aerogel (Hamzel®, Enova® IC3100 and GEA™ 0.125).

1.3 Problem Statement

About 7% of the 268 accidents that had occur worldwide in an aircraft in between 1997 to 2016, caused by an engine fire. There are three main causes of engine fire which are an exhaust system component failure, cylinder failure and defective maintenance. The problems that occur when an aircraft has an emergency landing is that a threat from an external jet-fuel, when the aircraft structure survive the crash but the main issue is fire penetration from the aircraft engine, due to the problem caused by the components used in the fire designated zones such as delamination of the fibres layer of the composite and lower temperature resistance of the composite. Also, weight, low strength, less resistant to impact, health issues, fatigue resistance, resistance to corrosion and moisture absorption were among the concerned issues on the properties of composites used in fire designated zone. Therefore, there is need to investigate further on the behaviour of the different composite in the standard flame, using a fibre-metal laminates composite and also, to investigate on mechanical, thermal and impact properties of composites.

At all times and all conditions, the component/material in fire designated zone of an aircraft engine structure need to be fireproof or fire resistant to ensure that the engine fire is protected. Therefore, fibre-metal laminate composites of synthetic and hybrid of synthetic/natural fibre (flax and kenaf) that has properties that are similar to synthetic fibre in terms of mechanical properties with less density, and composites of aluminium alloy coated with silica aerogel were fabricated in order to overcome the stated problems as compared with the existing properties of the materials based on the literature. All the components and fittings in the engine must be fireproof or fire resistant and protected from any leakages of flammable fluid during ignition (Rolls-Royce, 1996). This research focuses on achieving a less layered fire blanket composites based on aerogel coating and fibre-metal laminates with greener properties. This investigation was the first of its kind on fire designated zone of an aircraft engine. The investigation uses systematic techniques to find the solutions to the problems associated with composites through targeted objectives in the process of achieving a less thickness firewall composite with required mechanical, thermal and impact properties as compared with existing materials used as the bench mark based on the literature.

1.4 Research Questions

1. What are the fire behaviour properties of a fire designated zones of aircraft engine firewall?
2. What are the mechanical properties of composites that are fireproof or fire resistant in an aircraft engine fire designated zone?
3. What are the thermal properties of the composite materials used in an aircraft engine designated zone?
4. How does the impact affect the composite materials used in aircraft engine fire designated zone?

1.5 Objectives

The research was undertaken to investigate the detailed specific aspects of different composites using ISO2685 propane-air burner according to the standard, the research uses new materials for aircraft engine fire designated zone. The main objectives of this study are as follows:

(i). To investigates the fire behavioural properties of the fabricated fibre-metal laminate composites and composites of aluminium alloy coated with silica aerogel.
(ii). To investigate the tensile, compressive and flexural strength (mechanical properties) of the fabricated fibre-metal laminates for aero-engine application at high temperature.
(iii). To investigate the thermal performance (mass loss and visco-elastic) properties of fabricated fibre-metal laminate composites in a high-temperature application for fire designated zone of an aircraft engine.
(iv). To investigate the characteristic of velocity impact of the fabricated fibre-metal laminates composites in the fire designated zones of an aircraft engine.

1.6 Hypothesis

Fibre-metal laminates (FML) of aluminium alloy with synthetic (carbon fibre) and synthetic/natural (kenaf and flax) fibres, and aluminium alloy coated with silica aerogel, bound with epoxy resin/hardener polymer will produce a high strength and stiffer components, and will also produces a better heat resistance material, with good mechanical, thermal and impact properties that can delay the fire penetration from aircraft engine to aircraft fuselage, which will at least save aircraft passengers and crew lives, when used as components in the fire designated zone of an aircraft engine. It will act as the fireproof shield to the aircraft engine components that will prevent the flame from penetrating outside the engine**.**

1.7 Scope and Limitations

The scope of the research start with the developing composites that has low thermal conductivity, lightweight and fire resistance than the existing developed composites from the literature when considering fire designated zone of an aircraft engine. The work targets to achieve a greener composite and a less layered composite of aerogel-based coating using hand lay-up method. It devised a methodical approach to accomplish the research work by:

a. Establishing the fire behavioural performance of different structural materials in a pool-fire scenario. This was done by considering different types of fibre metal laminate composites and composites of aluminium alloy 2024-T3 coated with different types of silica aerogel and by observing their characteristics in pool-fire control with a flat panel burn-through test in accordance with the ISO2685:1998(E) standard.
b. By considering weither the tensile, compressive, flexural strength and other mechanical properties of the fibre metal laminate, will suit the location of fire designated zone of an aircraft engine.
c. Characterising the thermal properties of fibre metal laminate composites in terms of mass loss (thermogravimetric analysis) and visco-elastic properties of each fibre metal laminate composite was measured by mechanical dynamic analysis.
d. Absorbed energy and impact strength with specific perforation energy of the fibre metal laminate composites were analysed; whereby the impact strength, absorbed energy and specific perforation energy of the composites were in the range according to the existing literature.

This study, however, has certain limitations which need to be pointed out. Limited benchmark of literature on the composite materials used in fire designated zone of an aircraft engine as well as the method of coating the metal with silica aerogel. But still, the study, make a possible way of using a hand lay-up method by dissolving the aerogel in an epoxy resin using a mechanical stirrer and ultrasonic equipment.

1.8 Thesis Layout

This thesis comprises five chapters. Chapter one provides the brief introduction of the research work whereby the problem statements, objectives and the scope of the study was discussed. Chapter two mainly provides a literature review of the impact of composite materials. The review concentrates on different metals, alloys, natural fibres, aerogels, sandwich materials, firewall materials, and fire test, among others. Chapter three deal with the materials and method/methodology, which is divided into two parts. The first part is the materials selection, properties and apparatus used. The second part consists of the procedures of different tests carried out on the composites being researched and the solution of heat energy absorbed due to penetration of flame through the composites materials. Chapter four contains the results, findings and discussions on the experimental test undergone by the different composites. Also included in this chapter is the burner calibration test result. Lastly, chapter five consists of the detailed summary, conclusion, and recommendation for future work on this study.

REFERENCES

Abdullah, M., & Cantwell, W. (2006). The impact resistance of polypropylene-based fibre–metal laminates. *Composites Science and Technology, 66*(11), 1682-1693.

Abdullah, N., Abu Talib, A. R., Jaafar, A. A., Salleh, M. A. M., & Chong, W. T. (2010). The basics and issues of thermochromic liquid crystal calibrations. *Experimental Thermal and Fluid Science, 34*(8), 1089-1121.

Abdullah, N., Abu Talib, A. R., Saiah, H. R. M., Jaafar, A. A., & Salleh, M. A. M. (2009). Film thickness effects on calibrations of a narrowband thermochromic liquid crystal. *Experimental Thermal and Fluid Science, 33*(4), 561-578.

Abu Talib, A. R. (2003). Detailed Investigation of the Low- Temperature Anology of an Aircraft Engine Standard Fire-Test. *D.Phil Thesis, University of Oxford United Kingdom*.

Abu Talib, A. R., Neely, A. J., Ireland, P. T., & Mullender, A. J. (2005). Detailed investigation of heat flux measurements made in a standard propane-air fire-certification burner compared to levels derived from a low-temperature analog burner. *Journal of engineering for gas turbines and power, 127*(2), 249-256.

AC20-107A. (1984). Composite Aircraft Structures, Advisory Circular (AC) 20-107A, Federal Aviation Administration, US Department of Transportation, Washington, DC.

AC20-135. (1990). Draft Advisory Circular, Power Plant Installation and Propulsion System component Fire Protection Test Methods, Standards and Criteria, Advisory Circular No: 20-135.

Advisory, A. R. (2002). Department of Transportation. *Safety, 13*, 16.

Ainsworth, R., Allen, J., Davies, M., Doorly, J., Forth, C., Hilditch, M., Oldfield, M., & Sheard, A. (1989). Developments in instrumentation and processing for transient heat transfer measurement in a full-stage model turbine. *Journal of Turbomachinery, 111*(1), 20-27.

Aji, I., Sapuan, S., Zainudin, E., & Abdan, K. (2009). Kenaf fibres as reinforcement for polymeric composites: a review. *International Journal of Mechanical and Materials Engineering, 4*(3), 239-248.

Akimov, Y. K. (2003). Fields of application of aerogels (review). *Instruments and Experimental Techniques, 46*(3), 287-299.

Al-Oqla, F. M., & Sapuan, S. (2014). Natural fiber reinforced polymer composites in industrial applications: feasibility of date palm fibers for sustainable automotive industry. *Journal of Cleaner Production, 66*, 347-354.

Alderliesten, R., & Benedictus, R. (2008). Fiber/metal composite technology for future primary aircraft structures. *Journal of Aircraft, 45*(4), 1182-1189.

Alhuthali, A., Low, I. M., & Dong, C. (2012). Characterisation of the water absorption, mechanical and thermal properties of recycled cellulose fibre reinforced vinyl-ester eco-nanocomposites. *Composites Part B: Engineering, 43*(7), 2772-2781.

Antolovich, S. D., Busso, E. P., Skelton, P., & Telesman, J. (2016). High temperature materials for aerospace applications: Taylor & Francis.

Apte, V. (2006). *Flammability testing of materials used in construction, transport and mining*: Woodhead Publishing.

Ashori, A. (2008). Wood–plastic composites as promising green-composites for automotive industries! *Bioresource Technology, 99*(11), 4661-4667.

Askeland, D. R., & Phulé, P. P. (2006). *The science and engineering of materials*: Springer.

Asundi, A., & Choi, A. Y. (1997). Fiber metal laminates: an advanced material for future aircraft. *Journal of Materials Processing Technology, 63*(1-3), 384-394.

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

Azwa, Z., Yousif, B., Manalo, A., & Karunasena, W. (2013). A review on the degradability of polymeric composites based on natural fibres. *Materials & Design, 47*, 424-442.

Babu, M. G., Velmurugan, R., & Gupta, N. (2006). Energy absorption and ballistic limit of targets struck by heavy projectile. *Latin American Journal of Solids and Structures, 3*(1), 21-39.

Bartlett, J., & Stratford, C. (2001). Fire resistance certification of aircraft composite materials. *Practical Failure Analysis, 1*(6), 37-43.

Basri, M., Mazlan, N., & Mustapha, F. (2015). Effects of stirring speed and time on water absorption performance of silica aerogel/epoxy nanocomposite. *Journal of Engineering and Applied Sciences, 10*, 9982-9991.

Beumler, T., Pellenkoft, F., Tillich, A., Wohlers, W., & Smart, C. (2006). Airbus costumer benefit from fiber metal laminates. *Airbus Deutschland GmbH, 1*.

Bewlay, B., Nag, S., Suzuki, A., & Weimer, M. (2016). TiAl alloys in commercial aircraft engines. *Materials at High Temperatures, 33*(4-5), 549-559.

Bheekhun, N., Abu Talib, A. R., & Hassan, M. R. (2013). Aerogels in aerospace: an overview. *Advances in Materials Science and Engineering, 2013*.

Bheekhun, N., Talib, A. A., Mustapha, S., Ibrahim, R., & Hassan, M. (2016). *Towards an aerogel-based coating for aerospace applications: reconstituting aerogel particles via spray drying.* Paper presented at the IOP Conference Series: Materials Science and Engineering.

Bless, S., Rosenberg, Z., & Yoon, B. (1987). Hypervelocity penetration of ceramics. *International Journal of Impact Engineering, 5*(1), 165-171.

Blumm, J., Lindemann, A., & Schopper, A. (2008). Influence of the CNT content on the thermophysical properties of PEEK-CNT composites. *Thermophysical properties, 29*, 306-308.

Bocz, K., Szolnoki, B., Marosi, A., Tábi, T., Wladyka-Przybylak, M., & Marosi, G. (2014). Flax fibre reinforced PLA/TPS biocomposites flame retarded with multifunctional additive system. *Polymer degradation and stability, 106*, 63-73.

Botelho, E., Almeida, R., Pardini, L., & Rezende, M. (2007). Influence of hygrothermal conditioning on the elastic properties of Carall laminates. *Applied Composite Materials, 14*(3), 209-222.

Botelho, E. C., Silva, R. A., Pardini, L. C., & Rezende, M. C. (2006). A review on the development and properties of continuous fiber/epoxy/aluminum hybrid composites for aircraft structures. *Materials Research, 9*(3), 247-256.

Brazier, D., & Nickel, G. (1975). Thermoanalytical methods in vulcanizate analysis II. Derivative thermogravimetric analysis. *Rubber Chemistry and Technology, 48*(4), 661-677.

Brøndsted, P., Lilholt, H., & Lystrup, A. (2005). Composite materials for wind power turbine blades. *Annu. Rev. Mater. Res., 35*, 505-538.

Buenaño Andrade, A. M. (2009). *Diseño e instalación de equipos supervisores y sensores de temperatura para las unidades de generación de la Central Hidroeléctrica.* (D. Phil), QUITO/EPN/2008.

Bureau, A. S. (2015). Required Aircraft Inspections. *Aviation Safety Bureau*.

Burns, L. (2009). *Fire-Under-Load Testing of Carbon Epoxy Composites.* Paper presented at the 47th AIAA Aerospace Sciences Meeting including The New Horizons Forum and Aerospace Exposition.

Burroughs, M. (2011). *Effects of thermal cycling on epoxy bonded materials.* (D. Phil), Massachusetts Institute of Technology.

Cabo Pastor, M., Gallud Romero, L., Haya Fernández, C., & Peidro Puerto, J. Einsatz Von Polyetheretherketon (PEEK) FÜR Zahnimplantat -Prothesen.

Cahill, P. (1986). An Investigation of the FAA Vertical Bunsen Burner Flammability Test Method: Federal Aviation Administration Technical Center Atlantic City NJ.

Cantwell, W., Curtis, P., & Morton, J. (1986). An assessment of the impact performance of CFRP reinforced with high-strain carbon fibres. *Composites Science and Technology, 25*(2), 133-148.

Cantwell, W., Wade, G., Guilien, J., Jones, G.-V., & Compston, P. (2001). The high velocity impact response of novel fiber metal laminates. *ASME APPLIED MECHANICS DIVISION-PUBLICATIONS-AMD, 250*, 1-12.

Chang, P.-Y., Yeh, P.-C., & Yang, J.-M. (2008). Fatigue crack initiation in hybrid boron/glass/aluminum fiber metal laminates. *Materials Science and Engineering: A, 496*(1), 273-280.

Chawla, N., Kerr, M., & Chawla, K. (2005). Monotonic and Cyclic Fatigue Behavior of High-Performance Ceramic Fibers. *Journal of the American Ceramic Society, 88*(1), 101-108.

Cherry, R., & Warren, K. (1999). Fuselage Burnthrough Protection for Increased Postcrash Occupant Survivability: Safety Benefit Analysis Based on Past Accidents: DTIC Document.

Cho, M. D. (2013). Fused aerogel-polymer composite, methods of manufacture thereof and articles comprising the same: Google Patents.

Choi, I. (2016). Geometrically nonlinear transient analysis of composite laminated plate and shells subjected to low-velocity impact. *Composite structures, 142*, 7-14.

Chujo, Y. (1996). Organic—inorganic hybrid materials. *Current Opinion in Solid State and Materials Science, 1*(6), 806-811.

Clemens, H., & Kestler, H. (2000). Processing and applications of intermetallic γ-TiAl-based alloys. *Advanced engineering materials, 2*(9), 551-570.

Clyne, T., & Withers, P. (1995). *An introduction to metal matrix composites*: Cambridge University Press.

Corrales, F., Vilaseca, F., Llop, M., Girones, J., Mendez, J., & Mutje, P. (2007). Chemical modification of jute fibers for the production of green-composites. *Journal of Hazardous Materials, 144*(3), 730-735.

Cortes, P., & Cantwell, W. (2006). The prediction of tensile failure in titanium-based thermoplastic fibre–metal laminates. *Composites Science and Technology, 66*(13), 2306-2316.

Council, N. R. (1996). *New materials for next-generation commercial transports* (Vol. 476): National Academies Press.

D790-10, A. (2010). Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastic and Electrical Insulating Materials, ASTM International, West Conshohocken, PA, 2010, DOI: 10.1520/D0790-10.

D3039/D3039M-14, A. (2014). Standard Test Method forTtensile Properties of polymer matrix composite materials, ASTM Internationl, West Conshohocken, PA, 2014. DOI: 10.1520-D2029-D3039M-14.

D3410/D3410-16, A. (2016). Standard Test for Compressive of polymer Matrix Composite Material," with Unsupported Gage section by shear loading, ASTM International, West Conshohocken, PA, 2016, DOI: 10.1520/D3410_D3410M-16.

D7028-07, A. (2015). Standard Test Method for Glass Transition Temperature (DMA Tg) of Polymer Matrix Composites by Dynamic Mechanical Analysis (DMA), ASTM International, West Conshohocken, PA, 2015, DOI: 10.1520/D7028-07R15.

Dai, D., & Fan, M. (2014). Wood fibres as reinforcements in natural fibre composites: structure, properties, processing and applications. *Natural Fibre Composites: Materials, Processes and Properties*, 3-65.

Data, P. (2015). Technical Data Sheet. *Coordinates, 50*, 90.78.

Davies, G. (1996). Aircraft structures. *The Aeronautical Journal, 100*(1000), 522-529.

Davoodi, M., Sapuan, S., Ahmad, D., Aidy, A., Khalina, A., & Jonoobi, M. (2012). Effect of polybutylene terephthalate (PBT) on impact property improvement of hybrid kenaf/glass epoxy composite. *Materials Letters, 67*(1), 5-7.

Day, M., & Budgell, D. (1992). Kinetics of the thermal degradation of poly (phenylene sulfide). *Thermochimica acta, 203*, 465-474.

Day, R., & Rodrigez, J. C. (1998). Investigation of the micromechanics of the microbond test. *Composites Science and Technology, 58*(6), 907-914.

DeGarmo, E., Black, J., & Kohser, R. (2012). DeGarmo's Materials and Processes in Manufacturing, Chapter 18. *Powder metallurgy*, 481-506.

Díez-Pascual, A. M., Ashrafi, B., Naffakh, M., González-Domínguez, J. M., Johnston, A., Simard, B., Martinez, M. T., & Gómez-Fatou, M. A. (2011). Influence of carbon nanotubes on the thermal, electrical and mechanical properties of poly (ether ether ketone)/glass fiber laminates. *Carbon, 49*(8), 2817-2833.

Diller, T. (1993). Advances in heat flux measurements. *Advances in heat transfer, 23*, 279-368.

Dodds, N., Gibson, A., Dewhurst, D., & Davies, J. (2000). Fire behaviour of composite laminates. *Composites Part A: applied science and manufacturing, 31*(7), 689-702.

Duff, M., & Towey, J. (2010). Two Ways to Measure Temperature using thermocouples feature simplicity, accuracy, and flexibility. *Analog Dialogue, 44*(10), 1-6.

Dunlop, C. (2016). www.inspectapedia.com-Oil-Burner Date received 114/7/2016.

Eaton, H. E., Linsey, G. D., Sun, E. Y., More, K. L., Kimmel, J. B., Price, J. R., & Miriyala, N. (2001). *EBC Protection of SiC/SiC Composites in the Gas Turbine Combustion Environment: Continuing Evaluation and Refurbishment Considerations.* Paper presented at the ASME Turbo Expo 2001: Power for Land, Sea, and Air.

Evans, A. G., & Naslain, R. (1995). *High-temperature ceramic-matrix composites I: design, durability, and performance* (Vol. 1): Amer Ceramic Society.

FAA. (1990). *The Materials Fire Testing Handbook. DOT/FAA/CT-89/15. Atlantic City, N.J.: FAA Technical Centre.*

FAA. (2006). Department of Transportation Federal Aviation Administration (pp. 40).

Fan, J., Guan, Z., & Cantwell, W. J. (2011). Modeling perforation in glass fiber reinforced composites subjected to low velocity impact loading. *Polymer composites, 32*(9), 1380-1388.

Faruk, O., Bledzki, A. K., Fink, H.-P., & Sain, M. (2012). Biocomposites reinforced with natural fibers: 2000–2010. *Progress in Polymer Science, 37*(11), 1552-1596.

Fatima, S., & Mohanty, A. (2011). Acoustical and fire-retardant properties of jute composite materials. *Applied Acoustics, 72*(2), 108-114.

Fine, P. M., Cass, G. R., & Simoneit, B. R. (2004). Chemical characterization of fine particle emissions from the wood stove combustion of prevalent United States tree species. *Environmental Engineering Science, 21*(6), 705-721.

Forbes, M. P. L. (2005). Boiler Burners and Types of Burners. www.forbesmarshal.com Date received: 16/05/2016.

Fricke, J., & Emmerling, A. (1998). Aerogels—recent progress in production techniques and novel applications. *Journal of Sol-Gel Science and Technology*, *13*(1-3), 299-303.

Fricke, J., & Tillotson, T. (1997). Aerogels: production, characterization, and applications. *Thin Solid Films*, *297*(1), 212-223.

Gallo, E., Schartel, B., Acierno, D., Cimino, F., & Russo, P. (2013). Tailoring the flame retardant and mechanical performances of natural fiber-reinforced biopolymer by multi-component laminate. *Composites Part B: Engineering*, *44*(1), 112-119.

Gela, G., & Mitchell, D. (2000). *Assessing the electrical and mechanical integrity of composite insulators prior to live working.* Paper presented at the Transmission and Distribution Construction, Operation and Live-Line Maintenance Proceedings. 2000 IEEE ESMO-2000 IEEE 9th International Conference on.

Gorham, D., & Field, J. (1976). The failure of composite materials under high-velocity liquid impact. *Journal of Physics D: Applied Physics*, *9*(10), 1529.

Graupner, N., Herrmann, A. S., & Müssig, J. (2009). Natural and man-made cellulose fibre-reinforced poly (lactic acid)(PLA) composites: An overview about mechanical characteristics and application areas. *Composites Part A: applied science and manufacturing*, *40*(6), 810-821.

Gronauer, M., Kadur, A., & Fricke, J. (1986). Mechanical and acoustic properties of silica aerogel *Aerogels* (pp. 167-173): Springer.

Gross, J., & Fricke, J. (1992). Ultrasonic velocity measurements in silica, carbon and organic aerogels. *Journal of non-crystalline solids*, *145*, 217-222.

Gross, J., Fricke, J., Pekala, R., & Hrubesh, L. (1992). Elastic nonlinearity of aerogels. *Physical Review B*, *45*(22), 12774.

Gruner, K.-D. (2003). Principles of non-contact temperature measurement. *Raytek Company*.

Gudmundsson, S. (2013). *General aviation aircraft design: Applied Methods and Procedures*: Butterworth-Heinemann.

Hagenbeek, M. (2001). Impact properties. *Fibre–metal laminates: an introduction*.

Hammond, R., Proud, W., Goldrein, H., & Field, J. (2004). High-resolution optical study of the impact of carbon-fibre reinforced polymers with different lay-ups. *International Journal of Impact Engineering*, *30*(1), 69-86.

Hancox, N. (1981). *Fibre composite hybrid materials*: Applied Science London.

Hänninen, T., Thygesen, A., Mehmood, S., Madsen, B., & Hughes, M. (2012). Mechanical processing of bast fibres: The occurrence of damage and its effect on fibre structure. *Industrial Crops and Products, 39*, 7-11.

Hanu, L., Simon, G., Mansouri, J., Burford, R., & Cheng, Y. (2004). Development of polymer–ceramic composites for improved fire resistance. *Journal of Materials Processing Technology, 153*, 401-407.

Hapuarachchi, T. D., & Peijs, T. (2010). Multiwalled carbon nanotubes and sepiolite nanoclays as flame retardants for polylactide and its natural fibre reinforced composites. *Composites Part A: applied science and manufacturing, 41*(8), 954-963.

Hariram, S., Philipp, P., & Dummeyer, D. (2016). Fire Protection : Egines and Auxiliary Power Units. Boeing AeroMagazine, 14–19.

He, L., Li, X., Li, W., Yuan, J., & Zhou, H. (2012). A method for determining reactive hydroxyl groups in natural fibers: application to ramie fiber and its modification. *Carbohydrate research, 348*, 95-98.

Hidayat, A., & Tachibana, S. (2012). Characterization of polylactic acid (PLA)/kenaf composite degradation by immobilized mycelia of Pleurotus ostreatus. *International Biodeterioration & Biodegradation, 71*, 50-54.

Higgins, A. (2000). Adhesive bonding of aircraft structures. *International Journal of Adhesion and Adhesives, 20*(5), 367-376.

Homan, J. (2006). Fatigue initiation in fibre metal laminates. *International Journal of Fatigue, 28*(4), 366-374.

Hooijmeijer, P., & Vlot, A. (1998). Fibre Metal Laminates exposed to high temperatures. *Delft University of Technology, faculty of Aerospace Engineering*.

Horner, A. (2000). Aircraft Materials Fire Test Handbook, Test, (April). Retrieved from http://www.stormingmedia.us/17/1729/A172973.html: DTIC Document.

Hossain, S. I., Hasan, M., Hasan, M. N., & Hassan, A. (2013). Effect of chemical treatment on physical, mechanical and thermal properties of ladies finger natural fiber. *Advances in Materials Science and Engineering, 2013*.

Hugh, R. H. (2016). https://en.wikipedia.org/wiki/List_of_accidents_and_incidents_involving_airliners_by_location#Algeria.

Hull, D., & Clyne, T. (1996). *An introduction to composite materials*: Cambridge university press.

Hull, T. R., Witkowski, A., & Hollingbery, L. (2011). Fire retardant action of mineral fillers. *Polymer degradation and stability, 96*(8), 1462-1469.

Ismail, H., Rusli, A., & Rashid, A. (2005). Maleated natural rubber as a coupling agent for paper sludge filled natural rubber composites. *Polymer Testing, 24*(7), 856-862.

ISO2685. (1992). Aircraft Environmental conditions and test procedures for airborne equipment – Resistance to fire in designated fire zones. Switzerland.

ISO2685. (1998). Aircraft Environmental test procedures for airborne equipment – Resistance to fire in designated fire zones (pp. 29). 29.

Izani, M. N., Paridah, M., Anwar, U., Nor, M. M., & H'ng, P. S. (2013). Effects of fiber treatment on morphology, tensile and thermogravimetric analysis of oil palm empty fruit bunches fibers. *Composites Part B: Engineering, 45*(1), 1251-1257.

Jiang, D., Shen, W., & Wang, X. (1997). simulation of Impact Deformation, Damage and Fracture in Composite Laminates'. *Proceedings of the ICCM-XI, 2*, 583-593.

Jin, Z.-H., & Batra, R. (1996). Residual strength of centrally cracked metal/fiber composite laminates. *Materials Science and Engineering: A, 216*(1-2), 117-124.

John, M. J., & Thomas, S. (2008). Biofibres and biocomposites. *Carbohydrate polymers, 71*(3), 343-364.

Jones, T. (1977). Heat transfer, skin friction, total temperature, and concentration measurements. *Measurement of Unsteady Fluid Dynamic Phenomena, von Karman Institute for Fluid Dynamics*.

Joseph, P., Mathew, G., Joseph, K., Groeninckx, G., & Thomas, S. (2003). Dynamic mechanical properties of short sisal fibre reinforced polypropylene composites. *Composites Part A: applied science and manufacturing, 34*(3), 275-290.

Jumahat, A., Kasolang, S., & Bahari, M. (2015). Wear properties of nanosilica filled epoxy polymers and FRP composites. *Jurnal Tribologi, 6*, 24-36.

Kabir, M., Wang, H., Lau, K., & Cardona, F. (2012). Chemical treatments on plant-based natural fibre reinforced polymer composites: An overview. *Composites Part B: Engineering, 43*(7), 2883-2892.

Kaiser, A. (2017). Properties of Aluminium Alloy 2024-T3. Trentwood Works-Spokane WA 99215.

Kamat, R., Naik, G., & Verenkar, V. (2001). Synthesis and characterization of nickel manganite from different carboxylate precursors for thermistor sensors. *Analog Applications*(February), 52-56.

Kao, Y.-H. (2012). *Experimental investigation of NexGen and gas burner for FAA fire test.* (D. Phil), University of Cincinnati.

Kao, Y. H., Tambe, S. B., Ochs, R., Summer, S., & Jeng, S. M. (2017). Experimental study of the burner for FAA fire test: NexGen burner. *Fire and materials*.

Karout, A., Buisson, P., Perrard, A., & Pierre, A. (2005). Shaping and mechanical reinforcement of silica aerogel biocatalysts with ceramic fiber felts. *Journal of Sol-Gel Science and Technology, 36*(2), 163-171.

Kaushik, N., Kaushik, C., Sharma, S., & Sharma, J. (2007). Pollution hazards in polyester dyeing and role of acid in monitoring. *Current World Environment, 2*(2), 175-182.

Kaw, A. K. (2005). *Mechanics of composite materials*: CRC press.

Kemmish, D. (2010). *Update on the Technology and Applications of Polyaryletherketones*: ISmithers Canada.

Kennedy, G. J., Hansen, J. S., & Martins, J. R. (2011). A Timoshenko beam theory with pressure corrections for layered orthotropic beams. *International Journal of Solids and Structures, 48*(16), 2373-2382.

Khalil, H. A., Hassan, A., Zaidon, A., Jawaid, M., & Paridah, M. (2012). *Oil palm biomass fibres and recent advancement in oil palm biomass fibres based hybrid biocomposites*: INTECH Open Access Publisher.

Khan, S., Alderliesten, R., & Benedictus, R. (2009). Post-stretching induced stress redistribution in Fibre Metal Laminates for increased fatigue crack growth resistance. *Composites Science and Technology, 69*(3), 396-405.

Kim, H. M., Kim, H. S., Kim, S. Y., & Youn, J. R. (2015). Silica aerogel/epoxy composites with preserved aerogel pores and low thermal conductivity. *e-Polymers, 15*(2), 111-117.

Kim, J.-h., Lee, D.-w., Park, C. G., Bang, H.-c., Kim, J.-h., Cho, S.-y., Kim, Y.-i., & Baek, K.-y. (2008). *Construction of integrated simulator for developing head/eye tracking system.* Paper presented at the Control, Automation and Systems, 2008. ICCAS 2008. International Conference on.

Kimes, L., & Stanley, M. (1974). Aircraft engine installation: Google Patents.

Koltzenburg, S., Maskos, M., & Nuyken, O. (2014). *PolyMere: synthese, eigenschaften unD anWenDungen*: Springer.

Kourtides, D. A., Gilwee, W. J., & Parker, J. A. (1979). Thermochemical characterization of some thermally stable thermoplastic and thermoset polymers. *Polymer Engineering & Science, 19*(1), 24-29.

Kozaczuk, K. (2017). Engine nacelles design–Problems and challenges. *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, 0954410017706993.

Ku, H., Wang, H., Pattarachaiyakoop, N., & Trada, M. (2011). A review on the tensile properties of natural fiber reinforced polymer composites. *Composites Part B: Engineering, 42*(4), 856-873.

Langhelle, N. K., & Amdahl, J. (2001). *Experimental and numerical analysis of aluminium columns subjected to fire.* Paper presented at the The Eleventh International Offshore and Polar Engineering Conference.

Lattimer, B. Y., Ouellette, J., & Trelles, J. (2011). Thermal response of composite materials to elevated temperatures. *Fire Technology, 47*(4), 823-850.

Lawcock, G., Ye, L., Mai, Y., & Sun, C. (1998). Effects of fibre/matrix adhesion on carbon-fibre-reinforced metal laminates—I.: residual strength. *Composites Science and Technology, 57*(12), 1609-1619.

Lee, S. M. (1992). *Handbook of composite reinforcements*: John Wiley & Sons.

Lemay, J., Tillotson, T., Hrubesh, L., & Pekala, R. (1990). *Microstructural dependence of aerogel mechanical properties.* Paper presented at the MRS Proceedings.

Li, C., & Wu, W. (2017). Available online www. jsaer. com. *Journal of Scientific and Engineering Research, 4*(4), 208-220.

Li, S., & Zhong, Y. (2016). *A Turbofan-Engine Nacelle Shape Design and Optimization Method for Natural Laminar Flow Control.* Paper presented at the ASME Turbo Expo 2016: Turbomachinery Technical Conference and Exposition.

Liao, Y., Wu, H., Ding, Y., Yin, S., Wang, M., & Cao, A. (2012). Engineering thermal and mechanical properties of flexible fiber-reinforced aerogel composites. *Journal of Sol-Gel Science and Technology, 63*(3), 445-456.

Liu, H., Wu, Q., & Zhang, Q. (2009). Preparation and properties of banana fiber-reinforced composites based on high density polyethylene (HDPE)/Nylon-6 blends. *Bioresource Technology, 100*(23), 6088-6097.

Longo, F. (1992). Industrial guide—markets, materials, and applications for thermal-sprayed coatings. *Journal of Thermal Spray Technology, 1*(2), 143-145.

Lukkassen, D., & Meidell, A. (2003). Advanced materials and structures and their fabrication processes. *Narrik University College, Hin*.

Luo, H., Xiong, G., Ma, C., Chang, P., Yao, F., Zhu, Y., Zhang, C., & Wan, Y. (2014). Mechanical and thermo-mechanical behaviors of sizing-treated corn fiber/polylactide composites. *Polymer Testing, 39*, 45-52.

Lyon, R. E. (1997). Fire-resistant materials: research overview. Retrieved from http://www.fire.tc.faa.gov/pdf/ar97-99.pdf.: DTIC Document.

Machin, G. (2012). HiTeMS: A pan-European project to solve high temperature measurement problems in industry. *Measurement and Control, 45*(10), 315-318.

Mahjoub, R., Yatim, J. M., Sam, A. R. M., & Hashemi, S. H. (2014). Tensile properties of kenaf fiber due to various conditions of chemical fiber surface modifications. *Construction and Building Materials, 55*, 103-113.

Maier, C., & Calafut, T. (1998). *Polypropylene: the definitive user's guide and databook*: William Andrew.

Manhart, J., Kunzelmann, K. H., Chen, H. Y., & Hickel, R. (2000). Mechanical properties of new composite restorative materials. *Journal of biomedical materials research, 53*(4), 353-361.

Marissen, R. (1988). Fatigue crack growth in ARALL: A hybrid aluminium-aramid composite material: Crack growth mechanisms and quantitative predictions of the crack growth rates: Delft University of Technology.

Marissen, R., & Vogelesang, L. (1981). *Development of a new hybrid material: ARALL*. Paper presented at the Proceedings of the Second International SAMPE European Conference, Cannes, Frances.

Marker, T. R. (1999). Full-scale test evaluation of aircraft fuel fire burnthrough resistance improvements: DTIC Document.

Marker, T. R., Maloney, T., Lyon, R. E., & Safronava, N. (2014). Development of a Laboratory-Scale Flammability Test for Magnesium Alloys Used in Aircraft Seat Construction: DOT/FAA/TC-13/52.

Marsh, G. (2003). Next step for automotive materials. *Materials today, 6*(4), 36-43.

Marsh, G. (2010). Airbus A350 XWB update. *Reinforced plastics, 54*(6), 20-24.

Matthews, F., & Rawlings, R. (1999). Composites structures and materials: CRC Press, Boca Raton (FL).

May, C. (1987). *Epoxy resins: chemistry and technology*: CRC press.

Mendez, J., Vilaseca, F., Pelach, M., Lopez, J., Barbera, L., Turon, X., Girones, J., & Mutje, P. (2007). Evaluation of the reinforcing effect of ground wood pulp in the preparation of polypropylene-based composites coupled with maleic anhydride grafted polypropylene. *Journal of Applied Polymer Science, 105*(6), 3588-3596.

Miriyala, N., Fahme, A., & van Roode, M. (2001). *Ceramic Stationary Gas Turbine Program: Combustor Liner Development Summary*. Paper presented at the ASME Turbo Expo 2001: Power for Land, Sea, and Air.

Mishra, V., & Biswas, S. (2013). Physical and mechanical properties of bi-directional jute fiber epoxy composites. *Procedia Engineering, 51*, 561-566.

Mohammed , I., Abu Talib, A., Sultan, M., Mohammed, J., Ahmad, H., & Saadon, S. (2018). Mechanical Properties of Fibre Metal Laminates Made of Natural/Synthetic Fibre Composites *Bioresource. com, 13*(1), 2022-2034.

Mohammed, I., Talib, A. A., Sultan, M., & Saadon, S. (2016). *Temperature and heat flux measurement techniques for aeroengine fire test: a review*. Paper presented at the IOP Conference Series: Materials Science and Engineering.

Mohammed, I., Talib, A. A., Sultan, M., & Saadon, S. (2017). *Ballistic impact velocity response of carbon fibre reinforced aluminium alloy laminates for aero-engine*. Paper presented at the IOP Conference Series: Materials Science and Engineering.

Mohanty, A., Khan, M. A., & Hinrichsen, G. (2000). Surface modification of jute and its influence on performance of biodegradable jute-fabric/Biopol composites. *Composites Science and Technology, 60*(7), 1115-1124.

Mohanty, A., Misra, M., & Hinrichsen, G. (2000). Biofibres, biodegradable polymers and biocomposites: an overview. *Macromolecular materials and Engineering, 276*(1), 1-24.

Mooney, R., Lapin, J., Klimová, A., & McFadden, S. (2015). *Conditions for CET in a gamma TiAl alloy*. Paper presented at the IOP Conference Series: Materials Science and Engineering.

Moritis, G. (2003). Hubs, new technologies provide access to more deepwater reserves. *Oil & gas journal, 101*(44), 54-61.

Mouritz, A. (2006). Fire Safety of Advanced Composites for Aircraft, ATSB Research and Analysis Report. *Australian Transport Safety Bureau, Australian Government*.

Mouritz, A., Feih, S., Kandare, E., Mathys, Z., Gibson, A., Des Jardin, P., Case, S., & Lattimer, B. (2009). Review of fire structural modelling of polymer composites. *Composites Part A: applied science and manufacturing, 40*(12), 1800-1814.

Mrazova, M. (2013). Advanced composite materials of the future in aerospace industry. *INCAS Bulletin, 5*(3), 139.

Mullender, A. J., Handley, B. A., Coney, M. H., Ireland, P. T., & Neely, A. (2002). Model test apparatus and method: Google Patents.

Munday, J., & Gardiner, M. (2009). Fire investigation policies and practices in the UK. *Handbook of Forensic Science,* 254.

Murthy, A., Tsai, B. K., & Saunders, R. D. (1998). High-heat-flux sensor calibration using black-body radiation. *Metrologia, 35*(4), 501.

Mutasher, S. A. (2006). *Evaluation of mechanical properties of hybrid aluminium/fiber-reinforced composites.* (D. Phil.), Universiti Putra Malaysia.

Mutjé, P., Vallejos, M., Girones, J., Vilaseca, F., López, A., López, J., & Méndez, J. (2006). Effect of maleated polypropylene as coupling agent for polypropylene composites reinforced with hemp strands. *Journal of Applied Polymer Science, 102*(1), 833-840.

Nardecchia, S., Carriazo, D., Ferrer, M. L., Gutiérrez, M. C., & del Monte, F. (2013). Three dimensional macroporous architectures and aerogels built of carbon nanotubes and/or graphene: synthesis and applications. *Chemical Society Reviews, 42*(2), 794-830.

Naslain, R. (1995). High-Temperature Ceramic-Matrix Composites II: Manufacturing and Materials Developmen. *OH: Westerville,* 23-39.

Ning, F., Cong, W., Qiu, J., Wei, J., & Wang, S. (2015). Additive manufacturing of carbon fiber reinforced thermoplastic composites using fused deposition modeling. *Composites Part B: Engineering, 80,* 369-378.

O'donnell, A., Dweib, M., & Wool, R. (2004). Natural fiber composites with plant oil-based resin. *Composites Science and Technology, 64*(9), 1135-1145.

Oh, J. H., & Kim, Y. G. (1997). Optimum bolted joints for hybrid composite materials. *Composite structures, 38*(1), 329-341.

Parmenter, K. E., & Milstein, F. (1998). Mechanical properties of silica aerogels. *Journal of non-crystalline solids, 223*(3), 179-189.

Paul, A., Joseph, K., & Thomas, S. (1997). Effect of surface treatments on the electrical properties of low-density polyethylene composites reinforced with short sisal fibers. *Composites Science and Technology, 57*(1), 67-79.

Pekala, R., Alviso, C., Lu, X., Gross, J., & Fricke, J. (1995). New organic aerogels based upon a phenolic-furfural reaction. *Journal of non-crystalline solids, 188*(1), 34-40.

Peterson, J. D., Vyazovkin, S., & Wight, C. A. (2001). Kinetics of the thermal and thermo-oxidative degradation of polystyrene, polyethylene and poly (propylene). *Macromolecular Chemistry and Physics, 202*(6), 775-784.

Piccini, E., Guo, S. M., & Jones, T. V. (2000). The development of a new direct-heat-flux gauge for heat-transfer facilities. *Measurement Science and Technology, 11*(4), 342.

Pickering, K. (2008). *Properties and performance of natural-fibre composites*: Elsevier.

Platzer, K., Hirsch, C., Metzger, D., & Wittig, S. (1992). Computer-based areal surface temperature and local heat transfer measurements with thermochromic liquid crystals (TLC). *Experiments in fluids, 13*(1), 26-32.

Plueddemann, E. P. (1991). Chemistry of silane coupling agents *Silane coupling agents* (pp. 31-54): Springer.

Prabhakaran, R. D., Andersen, T. L., Markussen, C., Madsen, B., & Lilholt, H. (2013). *Tensile and compression properties of hybrid composites–a comparative study*. Paper presented at the Proceeding of the International Conference on Composite Materials.

Price, J., Jimenez, O., Parthasarathy, V., Miriyala, N., & Leroux, D. (2000). *Ceramic Stationary Gas Turbine Development Program—Seventh Annual Summary*. Paper presented at the ASME Turbo Expo 2000: Power for Land, Sea, and Air.

Price, T. L., Dalley, G., McCullough, P. C., & Choquette, L. (1997). Handbook: Manufacturing Advanced Composite Components for Airframes: DTIC Document.

Pullins, C. A. (2011). *High temperature heat flux measurement: sensor design, calibration, and applications.* (D. Phil.), Virginia Polytechnic Institute and State University.

Qiu, J., Zhang, C., Wang, B., & Liang, R. (2007). Carbon nanotube integrated multifunctional multiscale composites. *Nanotechnology, 18*(27), 275708.

Quintiere, J. G. (2006). *Fundamentals of fire phenomena*: Wiley Online Library.

Rajkumar, G., Krishna, M., Murthy, H., Sharma, S., & Mahesh, K. (2012). Investigation of repeated low velocity impact behaviour of GFRP/Aluminium and CFRP/Aluminium laminates. *Int J Soft Comput Eng, 1*(6), 50-58.

Rajkumar, G., Krishna, M., Narasimhamurthy, H., Keshavamurthy, Y., & Nataraj, J. (2014). Investigation of tensile and bending behavior of aluminum based hybrid fiber metal laminates. *Procedia Materials Science, 5*, 60-68.

Ramadhan, A., Talib, A. R. A., Rafie, A. S. M., & Zahari, R. (2012). *The behaviour of fibre-metal laminates under high velocity impact loading with different stacking sequences of Al alloy*. Paper presented at the Applied Mechanics and Materials.

Rawal, S. P. (2001). Metal-matrix composites for space applications. *JOM*, *53*(4), 14-17.

Ray, S. S., & Bousmina, M. (2005). Biodegradable polymers and their layered silicate nanocomposites: in greening the 21st century materials world. *Progress in materials science, 50*(8), 962-1079.

Razali, N., Sapuan, S., Jawaid, M., Ishak, M. R., & Lazim, Y. (2016). Mechanical and Thermal Properties of Roselle Fibre Reinforced Vinyl Ester Composites. *BioResources, 11*(4), 9325-9339.

Rehn, S. (2016). Impact of Altitude on Vertical Bunsen Burner Testing, DOT/FAA/TC-15/48, Federal Aviation Administration William J. Hughes Technical Center Aviation Research Division Atlantic City International Airport New Jersey 08405.

Reid, S., & Wen, H. (2000). *Perforation of FRP laminates and sandwich panels subjected to missile impact*: Woodhead Publishing Limited, Cambridge.

Rellick, G. S. (1992). Carbon and Graphite Matrices in Carbon-Carbon Composites: An Overview of their Formation, Structure, and Properties: DTIC Document.

Remmers, J., & De Borst, R. (2001). Delamination buckling of fibre–metal laminates. *Composites Science and Technology, 61*(15), 2207-2213.

Reyes, G., & Kang, H. (2007). Mechanical behavior of lightweight thermoplastic fiber–metal laminates. *Journal of Materials Processing Technology, 186*(1), 284-290.

Rogers, K., Sidey, G., & Kingston-Lee, D. (1971). Ballistic impact resistance of carbon-fibre laminates. *Composites, 2*(4), 237-241.

Rolls-Royce, p. (1996). *The Jet Engine 5th edition*.

Rouison, D., Sain, M., & Couturier, M. (2004). Resin transfer molding of natural fiber reinforced composites: cure simulation. *Composites Science and Technology, 64*(5), 629-644.

Rugg, D., Britton, T., Gong, J., Wilkinson, A., & Bagot, P. (2014). In-service materials support for safety critical applications–a case study of a high strength Ti-alloy using advanced experimental and modelling techniques. *Materials Science and Engineering: A, 599*, 166-173.

Runnels, J. N., & Fagerlund, K. R. (1983). Combustibly inert air supply system and method: Google Patents.

Sabet, A. R., Beheshty, M. H., & Rahimi, H. (2009). Experimental study of sharp-tipped projectile perforation of GFRP plates containing sand filler under high velocity impact and quasi-static loadings. *Polymer composites, 30*(10), 1497-1509.

Sadighi, M., Alderliesten, R., & Benedictus, R. (2012). Impact resistance of fiber-metal laminates: a review. *International Journal of Impact Engineering, 49,* 77-90.

Saheb, D. N., & Jog, J. (1999). Natural fiber polymer composites: a review. *Advances in polymer technology, 18*(4), 351-363.

Salman, S. D., Leman, Z., Sultan, M. T., Ishak, M. R., & Cardona, F. (2015). Kenaf/synthetic and Kevlar®/cellulosic fiber-reinforced hybrid composites: A review. *BioResources, 10*(4), 8580-8603.

Salman, S. D., Leman, Z., Sultan, M. T., Ishak, M. R., & Cardona, F. (2016). Ballistic impact resistance of plain woven kenaf/aramid reinforced polyvinyl butyral laminated hybrid composite. *BioResources, 11*(3), 7282-7295.

Samakrut, N., Krailas, S., & Rimdusit, S. (2008). Characterization of short glass fiber-reinforced PC/ABS blends. *Journal of Metals, Materials and Minerals, 18*(2), 207-211.

Samal, S. K., Mohanty, S., & Nayak, S. K. (2009). Polypropylene—bamboo/glass fiber hybrid composites: fabrication and analysis of mechanical, morphological, thermal, and dynamic mechanical behavior. *Journal of Reinforced Plastics and Composites, 28*(22), 2729-2747.

Sanders Jr, R. E. (2001). Technology innovation in aluminum products. *JOM, 53*(2), 21-25.

Sandler, J., Werner, P., Shaffer, M. S., Demchuk, V., Altstädt, V., & Windle, A. H. (2002). Carbon-nanofibre-reinforced poly (ether ether ketone) composites. *Composites Part A: applied science and manufacturing, 33*(8), 1033-1039.

Santhosh, J., Balanarasimman, N., Chandrasekar, R., & Raja, S. (2014). Study of properties of banana fiber reinforced composites. *International Journal of Research in Engineering and Technology, 3*(11), 144-150.

Saraswati, M., & Mahanum, A. (2008). Kenaf plant no longer a cheap agriculture raw material. *Bernama, http://www. ecerdc. com/ecerdc/getattachment/0fa0e21e-8860-4f05-996f-6dac1f036845/Kenaf-Plant-No-Longer-A-Cheap-Agriculture-Raw-Mate. aspx*.

Schmidt, M., & Schwertfeger, F. (1998). Applications for silica aerogel products. *Journal of non-crystalline solids, 225*, 364-368.

Schultz, D. L., & Jones, T. (1973). Heat-Transfer Measurements in Short-Duration Hypersonic Facilities: DTIC Document.

Schütze, M. (2016). High-temperature alloys: Single-crystal performance boost. *Nature materials*, *15*(8), 823.

Seferis, J. C. (1986). Polyetheretherketone (PEEK): Processing-structure and properties studies for a matrix in high performance composites. *Polymer composites, 7*(3), 158-169.

Seo, H., Hahn, H., & Yang, J.-M. (2008). Impact damage tolerance and fatigue durability of GLARE laminates. *Journal of engineering materials and technology, 130*(4), 041002.

Serge, N. L. (2008). Fire test on Components used in Fire Zones. Comparison of Gas Burner to Oil Burner AC20-135/ISO2685. (Atlantic City, New Jersey.).

Shalwan, A., & Yousif, B. (2013). In state of art: mechanical and tribological behaviour of polymeric composites based on natural fibres. *Materials & Design*, *48*, 14-24.

Shenglong, Y. S. D. (2005). A Glimpse at the Development and Application of Aluminum Alloys in Aviation Industry [J]. *Materials Review, 2*, 022.

Shevell, R. S., & Shevell, R. S. (1989). *Fundamentals of flight* (Vol. 2): Prentice Hall Englewood Cliffs, New Jersey.

Shinoj, S., Visvanathan, R., & Panigrahi, S. (2010). Towards industrial utilization of oil palm fibre: Physical and dielectric characterization of linear low density polyethylene composites and comparison with other fibre sources. *Biosystems engineering, 106*(4), 378-388.

Sikoutris, D. E. (2012). Fire Response of Composite Aerostructures. *D. phil Thesis, University of Patras, Greece*.

Sikoutris, D. E., Vlachos, D. E., Kostopoulos, V., Jagger, S., & Ledin, S. (2012). Fire burnthrough response of CFRP aerostructures. Numerical investigation and experimental verification. *Applied Composite Materials, 19*(2), 141-159.

Simon, H. (2017). Final Report, B777-300ER, Registration 9V-SWB Engine Fire AIB/AAI/CAS.122 Transport Safety Investigation Bureau Ministry of Transport.

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

Sircar, A., & Lamond, T. (1975). Identification of elastomers in tire sections by total thermal analysis. I. Tread and black sidewall. *Rubber Chemistry and Technology, 48*(2), 301-309.

Sivakumar, D., Ng, L., & Selamat, M. Z. (2017). Investigation on Fatigue Life Behaviour of Sustainable Bio-Based Fibre Metal Laminate.

Skhabovskyi, I., Batista, N. L., Damato, C. A., Reis, R. P., Botelho, E. C., & Scotti, A. (2017). Appraisal of fiber-metal laminate panels reinforced with metal pins deposited by CMT welding. *Composite structures*.

Smith, P. (2004). *Ask the pilot: everything you need to know about air travel*: Penguin.

Souza, P., Rodrigues, E., Prêta, J., Goulart, S., & Mulinari, D. (2011). Mechanical properties of HDPE/textile fibers composites. *Procedia Engineering, 10,* 2040-2045.

Sriramkumar, J. Mixture of Alloys Used for Building a Regenerator to Bring Down the Temperature of Liquid Hydrogen (Lh2) Below 20k.

Strong, A. B. (2008). *Fundamentals of composites manufacturing: materials, methods and applications*: Society of Manufacturing Engineers.

Su, L., Lu, C., Deng, G., Tieu, A., & Sun, X. (2013). Microstructure and mechanical properties of 1050/6061 laminated composite processed by accumulative roll bonding.

Suardana, N. P. G., Ku, M. S., & Lim, J. K. (2011). Effects of diammonium phosphate on the flammability and mechanical properties of bio-composites. *Materials & Design, 32*(4), 1990-1999.

Summers, P. T., Chen, Y., Rippe, C. M., Allen, B., Mouritz, A. P., Case, S. W., & Lattimer, B. Y. (2015). Overview of aluminum alloy mechanical properties during and after fires. *Fire Science Reviews, 4*(1), 3.

Sun, J., Deemer, C., Ellingson, W., & Wheeler, J. (2006). NDT technologies for ceramic matrix composites: Oxide and nonoxide. *Materials evaluation, 64*(1), 52-60.

Tamilarasan, U., Karunamoorthy, L., & Palanikumar, K. (2015). Mechanical Properties Evaluation of the Carbon Fibre Reinforced Aluminium Sandwich Composites. *Materials Research, 18*(5), 1029-1037.

Tan, C., Fung, B., Newman, J., & Vu, C. (2001). Organic aerogels with very high impact strength. *Advanced materials, 13*(9), 644-646.

Tanasa, F., & Zanoaga, M. (2013). Fiber-reinforced polymer composites as structural materials for aeronautics. *Sci. Res. Educ. Air Force, AFASES, 2*.

Tewarson, A. (1994). Flammability parameters of materials: ignition, combustion, and fire propagation. *Journal of Fire & Flammability, 12*(4), 329-356.

Thakur, V. K., & Thakur, M. K. (2014). Processing and characterization of natural cellulose fibers/thermoset polymer composites. *Carbohydrate polymers, 109*, 102-117.

thermochromic. (2018). http://www.tmchalcrest.com/technology-and-capability/liquid crystal.

Thermocouples. (2016). www.thermocoupleinfo.com/type-thermocouple.htm.

Thermometric, p. t. s. (2016). www.thermometricscorps.com/thermocouple.

Thomas, S., Paul, S., Pothan, L., & Deepa, B. (2011). Natural fibres: Structure, properties and applications *Cellulose Fibers: Bio-and Nano-Polymer Composites* (pp. 3-42): Springer.

Ticoalu, A., Aravinthan, T., & Cardona, F. (2010). *A review of current development in natural fiber composites for structural and infrastructure applications.* Paper presented at the Proceedings of the Southern Region Engineering Conference (SREC 2010).

Toho, T. (2011). Tenax Chopped Carbon Fibers, Toho Tenax America, Inc. 121 Cardiff Valley Road

Rockwood TN 37854 USA U.S. Export Administration Regulation.

Torres, F., & Cubillas, M. (2005). Study of the interfacial properties of natural fibre reinforced polyethylene. *Polymer Testing, 24*(6), 694-698.

Tran, K. D. (2001). *Light weight fire barrier materials for aircraft fuselage thermal/acoustical insulation.* Paper presented at the Federal Aviation Administration-Conference Fire Safety.

Tran, T. P. T., Bénézet, J.-C., & Bergeret, A. (2014). Rice and Einkorn wheat husks reinforced poly (lactic acid)(PLA) biocomposites: effects of alkaline and silane surface treatments of husks. *Industrial Crops and Products, 58*, 111-124.

Tranchard, P., Samyn, F., Duquesne, S., Estèbe, B., & Bourbigot, S. (2017a). Modelling behaviour of a carbon epoxy composite exposed to fire: Part I—Characterisation of thermophysical properties. *Materials, 10*(5), 494.

Tranchard, P., Samyn, F., Duquesne, S., Estèbe, B., & Bourbigot, S. (2017b). Modelling Behaviour of a Carbon Epoxy Composite Exposed to Fire: Part II—Comparison with Experimental Results. *Materials, 10*(5), 470.

Tranchard, P., Samyn, F., Duquesne, S., Thomas, M., Estèbe, B., Montès, J.-L., & Bourbigot, S. (2015). Fire behaviour of carbon fibre epoxy composite for aircraft: Novel test bench and experimental study. *Journal of Fire Sciences, 33*(3), 247-266.

Trevino, L. A., Orndoff, E. S., Tang, H. H., Gould, G. L., & Trifu, R. (2002). Aerogel-Based Insulation for Advanced Space Suit: SAE Technical Paper.

Turekova, I., Harangozo, J., Turnova, Z., & Balog, K. (2013). *Assessment of Functionality of Aged Cables at Loading by Heat Flux*. Paper presented at the Advanced Materials Research.

Uddin, F. (2016). Flame-retardant fibrous materials in an aircraft. *Journal of industrial textiles, 45*(5), 1128-1169.

Van de Weyenberg, I., Ivens, J., De Coster, A., Kino, B., Baetens, E., & Verpoest, I. (2003). Influence of processing and chemical treatment of flax fibres on their composites. *Composites Science and Technology, 63*(9), 1241-1246.

Van der Vegt, A., & Govaert, L. (2005). Polymeren. *Tc, 186*, 75.

Van Rijswijk, K., Brouwer, W., & Beukers, A. (2001). Application of natural fibre composites in the development of rural societies. *Delft: Delft University of Technology*.

Vega, T., Lattimer, B., & Diller, T. (2012). Temperature predictions using hybrid heat flux measured boundary conditions. *submitted to Fire Safety Journal*.

Vega, T., Lattimer, B. Y., & Diller, T. E. (2013). Fire thermal boundary condition measurement using a hybrid heat flux gage. *Fire safety journal, 61*, 127-137.

Vega, T., Wasson, R. A., Lattimer, B. Y., & Diller, T. E. (2015). Partitioning measurements of convective and radiative heat flux. *International Journal of Heat and Mass Transfer, 84*, 827-838.

Vilaseca, F., Valadez-Gonzalez, A., Herrera-Franco, P. J., Pèlach, M. À., López, J. P., & Mutjé, P. (2010). Biocomposites from abaca strands and polypropylene. Part I: Evaluation of the tensile properties. *Bioresource Technology, 101*(1), 387-395.

Virk, A. S. (2015). *Heat transfer characterization in jet flames impinging on flat plates.* (D. Phil), Virginia Tech.

Vlot, A., & Gunnink, J. W. (2011). *Fibre metal laminates: an introduction*: Springer Science & Business Media.

Voevodin, N., Grebasch, N., Soto, W., Kasten, L., Grant, J., Arnold, F., & Donley, M. (2001). An organically modified zirconate film as a corrosion-resistant treatment for aluminum 2024-T3. *Progress in Organic Coatings, 41*(4), 287-293.

Vogelesang, L., & Vlot, A. (2000). Development of fibre metal laminates for advanced aerospace structures. *Journal of Materials Processing Technology, 103*(1), 1-5.

Wanhill, R. (2013). *Aluminum-Lithium Alloys: Chapter 15. Aerospace Applications of Aluminum–Lithium Alloys*: Elsevier Inc. Chapters.

Warrier, A., Godara, A., Rochez, O., Mezzo, L., Luizi, F., Gorbatikh, L., Lomov, S. V., VanVuure, A. W., & Verpoest, I. (2010). The effect of adding carbon nanotubes to glass/epoxy composites in the fibre sizing and/or the matrix. *Composites Part A: applied science and manufacturing, 41*(4), 532-538.

Whitaker, S. (1972). Forced convection heat transfer correlations for flow in pipes, past flat plates, single cylinders, single spheres, and for flow in packed beds and tube bundles. *AIChE Journal, 18*(2), 361-371.

White, S. R., Sottos, N., Geubelle, P., Moore, J., Kessler, M. R., Sriram, S., Brown, E., & Viswanathan, S. (2001). Autonomic healing of polymer composites. *Nature, 409*(6822), 794-797.

Wickström, U., Jansson, R., & Tuovinen, H. (2009). Validation fire tests on using the adiabatic surface temperature for predicting heat transfer. *SP report, 19*.

Wise, J. A. (1976). Liquid-in-glass Thermometry. *Final Report National Bureau of Standards, Boulder, CO., 1*.

Wong, A.-Y., & Lam, F. (2002). Study of selected thermal characteristics of polypropylene/polyethylene binary blends using DSC and TGA. *Polymer Testing, 21*(6), 691-696.

Xia, Y., Wang, Y., Zhou, Y., & Jeelani, S. (2007). Effect of strain rate on tensile behavior of carbon fiber reinforced aluminum laminates. *Materials Letters, 61*(1), 213-215.

Xie, H., Wang, J., Xi, T., Liu, Y., Ai, F., & Wu, Q. (2002). Thermal conductivity enhancement of suspensions containing nanosized alumina particles. *Journal of Applied Physics, 91*(7), 4568-4572.

Xie, K., Liu, H., & Wang, X. (2009). Surface modification of cellulose with triazine derivative to improve printability with reactive dyes. *Carbohydrate polymers, 78*(3), 538-542.

Xie, Y., Hill, C. A., Xiao, Z., Militz, H., & Mai, C. (2010). Silane coupling agents used for natural fiber/polymer composites: A review. *Composites Part A: applied science and manufacturing, 41*(7), 806-819.

Yang, H.-S., Kim, H.-J., Son, J., Park, H.-J., Lee, B.-J., & Hwang, T.-S. (2004). Rice-husk flour filled polypropylene composites; mechanical and morphological study. *Composite structures, 63*(3), 305-312.

Yang, J., Kaliaguine, S., & Roy, C. (1993). Improved quantitative determination of elastomers in tire rubber by kinetic simulation of DTG curves. *Rubber Chemistry and Technology, 66*(2), 213-229.

Yang, X., Sun, Y., Shi, D., & Liu, J. (2011). Experimental investigation on mechanical properties of a fiber-reinforced silica aerogel composite. *Materials Science and Engineering: A, 528*(13-14), 4830-4836.

Ye, L., Lu, Y., Su, Z., & Meng, G. (2005). Functionalized composite structures for new generation airframes: a review. *Composites Science and Technology, 65*(9), 1436-1446.

Zhang, D., Sun, Y., Chen, L., Zhang, S., & Pan, N. (2014). Influence of fabric structure and thickness on the ballistic impact behavior of Ultrahigh molecular weight polyethylene composite laminate. *Materials & Design (1980-2015), 54,* 315-322.

Zhou, G. (1995). Prediction of impact damage thresholds of glass fibre reinforced laminates. *Composite structures, 31*(3), 185-193.

Zikre, H., & Bhatt, A. (2015). Comparison of mechanical properties of fiber reinforced plastic laminates compose with different thicknesses, manufacturing techniques and structures. *International Conference on Multidisciplinary Research & Practice*.