Faculty of Mechanical Engineering

MECHANICAL BEHAVIOUR OF CARBON REINFORCED POLYMER USING RTM AND VIP TECHNIQUES FOR AIRCRAFT SPOILER HINGE

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DECLARATION

I declare that this thesis entitled "Mechanical Behaviour of Carbon Reinforced Polymer using RTM and VIP Techniques for Aircraft Spoiler Hinge" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	………………………..
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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature	:	………………………………………………………
Supervisor Name	:	Assoc. Prof. Ir. Ts. Dr. Mohd Yuhazri Bin Yaakob
Date	:	……………………………………………………...

DEDICATION

Dedicated specially for

Beloved husband and family.

ABSTRACT

The existing hinge bracket for aircraft spoilers is mostly made of metallic materials. The change of the materials of the hinge bracket from metallic to composites can contribute to a low weight structure. The demand for fibre-reinforced plastic (FRP) composites in aircraft industries especially the hinge bracket for spoilers is increasing over the years. However, the current fabrication process for aircraft hinge brackets used as spoilers incurred high costs in terms of tooling, production, and testing cost. Therefore, in this thesis, flat panel with different number and orientation of woven carbon fibre layers in laminated composites system were used to determine its mechanical behaviour. Two different processes have been used, namely Resin Transfer Moulding Process (RTM) and Vacuum Infusion Process (VIP). The fabrication processes were used to fabricate FRP composite with different plies as parameters. The parameters used were 8, 16, 24 and 32 plies of woven carbon fibres. Besides that, the orientation of the carbon fibre remains constant which are [0/90]n and [45/-45]n. For the mechanical test, these FRP composites undergo tensile tests and flexural tests. From the experiment, it is shown that 8CF/EP composites fabricated using VIP have 10.6 % higher in specific strength obtained from the tensile test and 64.4 % higher in specific strength obtained from the flexural test. It is also indicated that the composites with 8 plies of carbon FRP composite fabricated by using VIP gave good tensile and flexural strength compared to the composites fabricated by using the RTM method. Moreover, 8 plies of carbon FRP gave better mechanical properties compared to other different plies of carbon FRP composite. A comparison of mechanical properties between FRP composites made by VIP with existing hinge for aircraft spoiler shows that the UTS of FRP composites is 58% lower than existing material; AA7075-T651.

ABSTRAK

Pendakap engsel sedia ada untuk kelepai pesawat kebanyakannya diperbuat daripada bahan logam. Perubahan bahan pendakap engsel dari logam ke komposit boleh menyumbang kepada struktur berat badan yang rendah. Permintaan untuk komposit plastik gentian bertetulang (FRP) dalam industri pesawat udara terutamanya dalam pendakap engsel untuk kelepai semakin meningkat mengikut perkembangan semasa. Namun begitu, proses fabrikasi semasa untuk pendakap engsel pesawat digunakan sebagai spoiler yang menanggung kos yang tinggi dari segi perkakas, pengeluaran, dan kos ujian. Oleh itu, tesis ini membentangkan kesan bilangan dan orientasi serat karbon yang berlainan lapisan dalam sistem komposit berlapis berhubungan dengan sifat-sifat mekaniknya. Dua proses yang berbeza telah digunakan iaitu Proses Pembendungan Pemindahan Resin (RTM) dan Proses Penyedutan Vakum (VIP). Proses fabrikasi digunakan untuk membuat komposit FRP dengan lapisan yang berlainan sebagai parameter. Parameter yang digunakan ialah 8, 16, 24 dan 32 helai gentian karbon tenunan. Selain itu, orientasi serat karbon kekal tetap sedemikian rupa sehingga [0/90] n. Bagi ujian mekanikal, komposit FRP ini menjalani ujian tegangan dan ujian lenturan. Daripada eksperimen ini, ianya menunjukkan komposit 8CF/EP yang direka menggunakan VIP mempunyai 10.6% lebih tinggi dalam kekuatan tertentu yang diperolehi daripada ujian tegangan dan 64.4% lebih tinggi dalam kekuatan tertentu yang diperolehi dari ujian lenturan. Ia juga menunjukkan bahawa komposit dengan 8 lapisan karbon FRP komposit yang direka dengan menggunakan VIP memberikan kekuatan tegangan dan lenturan yang baik berbanding dengan komposit yang direka dengan menggunakan kaedah RTM. Lebih-lebih lagi, FRP komposite dengan 8 helai karbon memberikan sifat mekanikal yang lebih baik berbanding dengan lain-lain sebatian karbon komposit FRP. Perbandingan sifat mekanik antara komposit FRP yang dibuat oleh VIP dengan braket engsel sedia ada untuk spoiler pesawat, menunjukkan bahawa UTS komposit FRP adalah 58% lebih rendah daripada bahan sedia ada; AA7075-T651.

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A	-	Area
b	-	Width of the specimen
d	-	Depth of beam, mm
E_f	-	Modulus of elastic in bending, MPa
F	-	Force
L	-	Length of the support span, mm
m	-	Slope of the tangent to the initial straight line portion of the load deflection curve, N/mm
R	-	Rate of cross head motion, mm/min
tl	-	Total length
t	-	Thickness of the specimen, mm
w	-	Modulus of elastic in bending, MPa
Z	-	Rate of straining of the entire fibre mm/mm/min

LIST OF ABBREVIATIONS

AFRP	- Aramid Fibre Reinforced Polymer
ASTM	- American Society for Testing and Materials
CFRP	- Carbon Fibre Reinforced Polymer
CMC	- Ceramic Matrix Composites
CTRM	- Composites Technology Research Malaysia Sdn. Bhd
FACC	- Fischer Advanced Composites Components
FRP	- Fibre Reinforced Composite
FTIR	- Fourier Transform Infrared Spectroscopy
GFRP	- Glass Fibre Reinforced Polymer
MMC	- Metal Matrix Composites
PEEK	- Polyether Ether Ketone
PLA	- Polylactic Acid
PMC	- Polymer Matrix Composites
PP	- Polypropylene
PVC	- Polyvinylchloride
RTM	- Resin Transfer Moulding
SEM	- Scanning Electron Microscope
UD	- Unidirectional
VARTM	- Vacuum Resin Transfer Moulding
VIP	- Vacuum Infusion Process
1CF/EP	- 1 Carbon Fibre/Epoxy
8CF/EP	- 8 Carbon Fibre/Epoxy
16CF/EP	- 16 Carbon Fibre/Epoxy
24CF/EP	- 24 Carbon Fibre/Epoxy
32CF/EP	- 32 Carbon Fibre/Epoxy

LIST OF PUBLICATIONS

JOURNAL:

1. Yuhazri, M.Y., Zailinda, A., Amirhafizan, M.H., Sihombing, H., and Lau, S.T.W., 2019. Effects of Different Processes on Mechanical Properties of CFRP by RTM and VIP Techniques. *International Journals of Engineering and Sciences*, 19 (5), pp. 98-103.

PROCEEDING:

1. A. Zailinda, A. Rivai, Yuhazri, M.Y., & M.K.M. Rus, Comparison of Two Different Composite Process Using Hand Lay UP and Resin Transfer Moulding for Tensile Properties. *Proceeding of Mechanical Engineering Day 2017, Melaka, 30 March 2017*, pp. 308-309.

CHAPTER 1

INTRODUCTION

1.1 Background

Fibre Reinforced Plastics (FRP) composite materials have many advantages; such as lightweight, high strength, high-temperature resistance, and corrosion resistance. Due to the advantages of FRP, it has been applied in transportation which requires lightweight materials to save fuel consumption and improve acceleration (Sai, 2016). Composite is made of a combination of two or more materials with different properties. FRP composites consist of fibre or reinforcement bound into another material called a matrix. Matrix binds the fiber together like an adhesive and makes them stronger or more resistant towards external damage. The fibre reinforces the matrix to become stronger and stiffer and helps to resist cracks and fractures. The main functions of fibres are to carry the load and provide stiffness, strength, thermal stability, high ultimate strength, low variation among fibre, high stability of their strength during alignment of the fibres, protection from damage during manufacture and manipulation. The environment influences the durability of composites for the protection. Generally, a composite material is composed of reinforcement such as fibres, flakes, or fillers embedded in a matrix such as polymers, metals or ceramic to improve the overall mechanical properties of the matrix (Nagavally, 2017).

There are few types of fibres such as glass, carbon, carbide, and asbestos while the matrix usually used plastic, ceramic and metal. From these three types of matrix, it produces three groups of a composite including polymer matrix composites (PMCs), ceramic matrix composites (CMCs), and metal matrix composites (MMCs). There are three types of composites namely particulate composite, fibre-reinforced composite, and a sandwich or laminate composite. Particulate composite composed of a particle of one or more material to become a stronger material. For fibre-reinforced composites, it consists of long or short fibre which is embedded in the matrix. The fibre can be in aligned continuous, aligned discontinuous or random direction of fibre orientation. While for the sandwich composite or laminated composite, they consist of layers of two or more different materials that are bonded together to make a stronger material. The behaviour of laminated composites is usually affected by the fibre angle or fibre orientation and the arrangements of the layers.

As mentioned by Papargyris et al., (2008), fibre reinforced polymer composites have gained substantial interest over the past decades, this is due to their very high strength of weight and stiffness to weight ratio which led to the application of composites materials in many industries such as aerospace and automotive industries. Carbon fibre reinforced polymer (CFRP) possesses a high strength and stiffness to weight ratio, excellent fatigue behaviour and corrosion resistance, quick application and relatively short construction time (Le-Trung et al., 2010). Apart from CFRP, there are some other types of fibre reinforced composite (FRP) such as carbon (CFRP) and glass (GFRP) (Sonnenchein et al., 2016).

The primary manufacturing process to produce composites includes manual lay-up, spray-up, filament winding, pultrusion, autoclave, and resin transfer moulding. Autoclave is one of the processes that is widely used in aerospace industries because this process can contribute a high volume of composite production. But autoclave process has some weaknesses which are high tooling cost and low flexibility to design changes. Due to this problem, new process is being investigated and reviewed. The selected processes are resin transfer moulding (RTM) and vacuum infusion process (VIP). RTM has a lot of advantages such as low tooling cost, good dimensional tolerances, possibility to mould high complex shape, and have good surface finish on both sides of the composites. RTM has proved to a viable and competitive technique for fabrication of large, complex and high performance FRP composite materials (Richardson and Zhang, 2000). RTM process involves five important components which are the resin and catalyst container, pumping unit, mixing chamber, resin injector, and mould. Parameters that affect RTM process are the mould which is used to pave the fibres, injection pressure, temperature, viscosity, volume fraction, mould filling time, and resin curing time.

Vacuum infusion process (VIP) is a process that uses vacuum pressure to flow the resin into a laminate. The material or the reinforcement are placed in the mould and the vacuum pump is connected before the resin is inserted. Once the vacuum has completely achieved, the resin flow through the positioned tubing will automatically sucked up into the laminate (Abdurohman et al., 2018). VIP has several advantages such as better consistency, higher specific strength and rigidity, good interior finish and has faster cycle time and low cost. Besides that, other advantages include less wasted resin, unlimited setup time, high consistency and repeatability, cleaner process than traditionally FRP processing and ability to use standard composite tooling which is as long as the tool can hold a vacuum and flanges is wide enough to seal the bag (Reeve, 2018).

In RTM and VIP, laminated composite type will be used. Fibre is the primary load carrying element of the composite. The strength and stiffness of composite is in the direction of the fibres while the matrix supports the fibres and bonds them together in the composite materials. The matrix transfers all the applied loads to the fibres and keeps the fibres in their position and orientation. Fibre orientation directly impacts the mechanical the properties of composite since it is required to stack as many layers as possible in the carried main load and this approach may be applied for some structures with different directions of fibres such as 0°, +45°, -45°, and 90° directions. The stacking sequences of the fibre layers describe the distribution of ply orientations through the laminate thickness. The higher the numbers of fibre plies with preferred orientations, the more stacking sequences are possible to design. The strength and stiffness of the composites build up depends on the orientation sequence of the plies. The composites required 0° plies in order to react to axial loads, while ±45° plies to react with shear loads, and 90° plies to react to side loads. This is due to the strength design requirements are the function of applied load direction, ply orientation and ply sequence must be correct. There are few types of fibre orientation namely as unidirectional, bidirectional (fabric), and non-woven (knitted or stitched). Generally, for aerospace structures, woven fabrics are usually used in order to save weight, minimize and used of resin, use in maintaining the fibre orientation during fabrication process.

1.2 Problem statement

Nowadays, composite has increased in replacing the conventional materials and widely applied in various field such as aerospace structures and automotive parts. Aerospace industries require high volume of composite production and autoclaves process is one of the manufacturing processes that are widely used in these industries. But the weakness of this process is it requires high tooling cost and low flexibility to design changes. In aerospace industries, it shows high demand of composite manufacturing. The interest of composite materials in aircraft structures comes from the action to reduce fuel consumption in the commercial airlines Airbus and Boeing. For an instance, both have been competing to increase their aircraft (Mun et al., 2014).

The performance of an aircraft is mainly depending on the lightweight of component, so the design of an aircraft is impacted by the interaction of its functional necessity and its basic strength, stiffness, and life requirements. There are limitation for doing smart design using metals in order to meet the specification of better performing design which is composites material called carbon fibre reinforced plastic (CFRP), is explored for the usage in aircraft part (Kalanchiam and Chinnasamy, 2012). Besides, most of the existing aircraft parts are made of metals. According to (Laurenzi and Marchetti, 2012), the global objective is to reduce to half the amount of fuel by 2020 and further improve to 70% less by 2025, for example it is one of the most efficient aircraft which entirely made of carbon fibre. In aerospace industries, it requires high volume of production and the compression moulding process produces low cost parts but requires a high capital investment in presses, infrastructure and tooling.

Aircraft use spoilers arranged on the upper surface of wings, which are used during the flight to manoeuvre the aircraft and hinge moves the spoiler upwards and downwards with a hydraulic cylinder in relation to the wing. The hinge bracket is the structure which attached to the aircraft spoiler mounted at the top of the aircraft wings and the hinge which allows the upward and downward movement of the aircraft spoilers. The location of the hinge bracket is between the spoiler and the wing, one of the brackets is attached to the spoiler while the other is joint to the wing (Mun et al., 2014). Existing hinge for aircraft spoilers is mostly made of metals. Composite hinge is still not well developed and not fully utilised in commercial aircraft due to a few barriers including manufacturing cost, non-recurring development costs, maintenance technology, as well as difficulty in determining and analysing the mechanical behaviour of composite hinge.

The conventional method in determining the mechanical behaviour of composite hinge is by using destructive testing which is tough, timely and material consuming which in return increases the difficulty in design optimisation of the composite hinge. The arrangement and the orientation for actual hinge provided by CTRM were used in this