PARAMETRIC STUDIES OF VBO-OVEN CURE PROCESS ON THE BONDING QUALITY OF SANDWICH PANEL

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by

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List of Abbreviations

ANOVA	:	Analysis of Variance
ASTM	:	American Society for Testing and Materials
DOE	:	Design of Experiment
Evac	:	Evacuation channel
ICP	:	Internal core pressure
OOA	:	Out-of-Autoclave
PTFE	:	Polytetrafluoroethylene
PW	:	Plain weave
RML	:	Resin Mass Loss
UD	:	Unidirectional
VBO	:	Vacuum Bagging Only
PVC	:	Poly-vinylchloride
PUR	:	Polyeurethane

KAJIAN PARAMETRIK BERKAITAN PROSES PEMBUATAN VBO-KETUHAR TERHADAP IKATAN KUALITI SANDWIC PANEL

ABSTRAK

Keinginan yang kuat untuk mengurangkan kos pengeluaran dalam industri aeroangkasa telah menciptakan potensi untuk menghasilkan komposit dengan OOA (out-of-autoclave) yang menggunakan tekanan vakum dan proses pembuatan di dalam ketuhar sahaja. Bagaimanapun, proses tersebut yang menggunakan bahan-bahan OOA prepreg yang mahal sebagai kulit teras sandwic komposit, telah menyebabkan kesamaan di dalam kos pengeluaran secara keseluruhan. Sebagai langkah ke arah kos struktur pembuatan sandwic yang optimum, fokus penyelidikan ini akan tertumpu terhadap kesan-kesan proses pembuatan OOA-ketuhar dengan kulit teras konvensional autoklaf prepreg. Empat parameter pemprosesan OOA-ketuhar telah disiasat; pemampatan vakum sebelum pembuatan, penggudaran di pinggir sandwich komposit dan jenis-jenis pelapik acuan berbeza. Eksperimen telah dirancang menggunakan dua fasa, Rekabentuk faktorial penuh Eksperimen. Sebelum penghasilan sandwich komposit, ujian tekanan teras dalaman telah dijalankan untuk melihat hubungan di antara pemampatan vakum sebelum pembuatan mengikut standard industry, dengan tekanan teras dalam sandwich komposit. Kualiti panel komposit kemudiannya dianalisis dari segi kehilangan jisim resin selepas proses pembuatan, pembentukan kawasan resin di antara kulit teras dan inti sarang lebah dan kualitinya, dan akhirnya kekuatan resin diantara kulit teras-inti sarang lebah diuji menggunakan ujian tegangan. Kesemua keputusan yang diperolehi kemudiannya dianalisa meggunakan analisis statistik varians. Daripada hasil ujian

terhadap panel komposit, dapat diperhatikan bahawa pembentukan kawasan resin di antara kulit teras dan inti sarang lebah mempunyai kesan yang paling menonjol pada kekuatan ikatan antara muka panel. Peningkatan pembentukan kawasan resin menyumbang terhadap peningkatan tenaga yang diserap semasa kegagalan dan menghasilkan kekutan ikatan muka panel yang lebih tinggi. Didapati bahawa pembentukan kawasan resin juga dipengaruhi oleh kehilangan jisim resin selepas proses pembuatan. Ianya telah dikenal pasti bahawa penggudaran di pinggir sandwich komposit dan jenis pelapik acuan yang tidak berlubang menyumbang kepada pembentukan kawasan resin dan kehilangan jisim resin yang optimal.

PARAMETRIC STUDIES OF VBO-OVEN CURE PROCESS ON THE BONDING QUALITY OF SANDWICH PANEL

ABSTRACT

A strong desire to reduce manufacturing costs in the aerospace industry has created the potential to manufacture composites with OOA (out-of-autoclave) vacuum pressure only-oven curing process. However such process that is coupled with OOA prepreg materials caused monotony in the overall production cost as the material is expensive. As a step towards cost optimum of sandwich structures manufacturing, this research focuses on the effects of OOA-oven curing process with existing conventional autoclave prepreg material. Four OOA-oven cure processing parameters were investigated; debulking, edge breather, non-perforated (solid and PTFE release film) and perforated release film. The experiment was planned using two levels, full factorial Design of Experiments. Prior to curing, an ICP (internal core pressure) test was conducted to investigate the relation between standard industrial debulking with ICP. Once cured the panels quality was analysed in terms of their RML (resin mass loss) after cure, resin fillet formation quantity (area) and quality (void), and finally their skin-core interfacial strength was analysed using tensile test. All of the obtained results were then analysed using statistical analysis of Variance. Primarily, it was observed from the test results that resin fillet area formation had the most prominent effect on the panel interfacial bonding strength. As the fillet area increased, more energy was absorbed during fracture thus yield a higher interfacial tensile strength. Consecutively, resin fillet area formation was

influenced by the RML during curing. Subsequently it was identified that edge breather and non-perforated release film are the two processing parameters that contributed to both optimum RML and resin fillet area formation.

CHAPTER 1

INTRODUCTION

1.1 Introduction to composite

The term 'composite' generally refers to combinations of two or more materials that yield superior properties by taking advantage of each material exceptional characteristics. In the field of structural engineering, the two most common constituents that made up composite materials are fibre reinforcement and polymeric matrix. The main benefits of fibre reinforcement are their high specific strength (strength to weight ratio) and specific modulus (modulus to weight ratio). Tensile strength comparison between glass fibre reinforcement and most of bulk metal materials have shown that, the reinforcement strength was exceedingly higher by almost three fold (Gibson, 2012). Hence during service, most of the tensile and compression load will be carried by the fibre.

Conversely, polymeric matrix materials are very weak in comparison. Nonetheless, it aids in binding the reinforcements and distributes the applied loads among the reinforcements during tension. Additionally, it also stabilizes the fibres and prevents them from buckling in compression. Polymeric matrix also acts as primary load carrier for interlaminar shear and protects the reinforcements from the environments and handlings (Gay et al., 2002).

Composites have the greatest impact in the commercial aircraft application. Aircraft unlike other vehicle are more critical towards both weight and safety issues. Their design must meet a standard performance and numerous safety criteria while maintaining an allowable overall weight, in order to reduce drag and maintain durability. By using composite materials, the aircraft parts design can be manipulated by integrating required fasteners thus created a single cured assembly part, that are about 20-30% lighter than the conventional metal counterparts. Consequently, reducing the number of detail parts and assembly cost significantly, as assembly labour can amount for approximately 50 percent of the cost of an airframe. Despite the simplification, it still maintained its optimum strength and stiffness, with improved fatigue life and corrosion resistance. As the composite industry evolved and the aircraft industries become more advanced and competitive, the demands for lighter aircraft parts that can boost its performance became a priority. Therefore in such high-end industries where weight is one of the key factors, most of the parts are made of not only monolithic composite but also from sandwich composite which gave elevated performance at lower relative weight.

1.2 Sandwich composite

Sandwich composite constitutes of three main constituent materials, thin upper and lower skins separated by a thicker low density core, bonded commonly using adhesive film (Wang and Yang, 2000). Its I-beam resemble-like construction provides it with great stability and stiffness-to-weight ratio when subjected to flexural load as well as excellent strength-to-weight ratio when subjected to in-plane loading (Sezgin et al., 2009, Othman and Barton, 2008). The skins of the sandwich composite mostly carry membrane loading whereas the core carry shear load. One of the main advantages of sandwich composite is definitely its high stiffness and strength to weight ratio.

It was reported that an integration of core in sandwich structure, causes an increase in the bending stiffness and strength by magnitude of 7 and 3.5, respectively with an increment of only 0.03 in its relative weight, when compared to monolithic composite laminate (Petras, 1998). Furthermore, when the core thickness is doubled, the structure relative stiffness escalated dramatically by 5 folds and its relative strength doubled, with yet an increase in the relative weight of only 0.03. These simple twitches that bring enormous advantage have attracted major aviation industries such as Airbus to utilise composite materials in most of its aircraft parts design (Ye et al., 2005).

A comprehensive review of the usage of composite materials in aircraft manufacturing had been well reported and documented in the works of Ye et al. (2005) and Soutis (2005). The design of fully composite vertical stabilizer of A310 and horizontal stabilizer of A320 aircraft models contributed to a total weight saving of 400 kg and 800 kg respectively (Ye et al., 2005). A saving in terms of total aircraft weight is very critical to assess the efficiency of the aircraft design in fuel consumption as the reduction in overall fuel costs may contribute towards commercial competitive advantage over many aircraft designs in the market. It has been estimated that with a reduction of 1 kg weight has enabled an increase in fuel saving of 2900 litre per year and subsequently has a significant reduction in the overall operating costs (Soutis, 2005, Ye et al., 2005).

In aircraft application, the most common sandwich skin materials being used as reinforcements are carbon and glass (E-glass, S-Glass). Reason being, carbon has very good stiffness performance but poor toughness performance, while glass performance behave contrarily (Gupta et al., 2002, Alkovali, 2001). Under flexural loading, carbon reinforcement which possessed higher flexural and elastic moduli can provide better bending stiffness to the panel and withstand higher bending load with smaller deflection. However, carbon reinforcements are very expensive as compared to other reinforcements (Hossain, 2011). This reinforcement generally existed in two standards forms which are dry fabric and prepreg with its variant; OOA prepreg, Autoclave prepreg and semipreg. Prepreg means that the reinforcement is pre-impregnated with a controlled amount of resin, whereas dry fabric reinforcement required resin infusion during its manufacturing process (Rion et al., 2008, Gupta et al., 2002). The type of skin materials chosen will dictate the type of suitable core for sandwich structure and simultaneously its manufacturing process.

On the other hand sandwich core can be commonly divided to two types; which is closed cell core such as balsa, foam core, synthetic core etc and open cell core such as honeycomb, corrugated core, etc. (Yongqiang and Feng, 2010). Open cell core, precisely honeycomb are used extensively in the aeronautical industry, particularly because it offers the best stiffness to weight ratio by manipulating it design. Its cellular solid construction makes used of porosity per unit cell to reduce its overall weight whilst maintaining quality of stiffness (Rion et al., 2008). These sandwich composite constituents; sandwich skin and core, can be manufactured through various potential methods

The manufacturing process of sandwich composite materials usually differs from one application to the other. The process is influenced by many factors such as design and desired characteristic of the structure, production rate, cost and etc. In general, the processes available for sandwich composite manufacturing can be categorised to two groups, which were autoclave and out-of-autoclave (OOA). OOA process simply referred to any processes that do not require curing in an autoclave, such as; filament winding, pultrusion, compaction moulding, liquid moulding, oven curing and etc, each manufacturing processes has its advantage and is used for specific applications. Nonetheless, for sandwich composite primarily two OOA process were commonly in practice which were liquid moulding and oven curing.

1.3 Problem statement

In critical industry such as aerospace, manufacturing process of each part are done carefully in order to ensure their optimum performance and quality. Currently in the industry, most sandwich composite parts are fabricated by sandwiching honeycomb core with autoclave prepreg (Rion et al., 2008). These constituent's are then cured in an autoclave, where high application of pressure retained the sandwich quality by collapsing voids that formed within the structure, thus produced a final product with void content less that 1% (Tavares et al., 2010b). However, the time consuming pressurisation process restricted the allowable structures design and escalated the total operating cost (Joseph and Viney, 2000).

The current existed solution is to omit the high pressure and allowed the part to be cured under atmospheric pressure only, using oven curing process. The exclusion of high pressure within the process do allows a more flexible structure design with lower overall operating cost, however void dissolution becomes difficult and simultaneously effect structure mechanical quality (Crump et al., 2010). Therefore, to counter this issue, a new prepreg namely OOA (out-of-autoclave) prepreg was designed to suit the oven cure process that can produce final product with autoclave cured quality (Grunenfelder and Nutt, 2010). Albeit this, OOA prepreg are very expensive as compared to autoclave prepreg (Hanafiah, 2013). Ultimately, both processes became monotony, since shift from autoclave to oven curing do lower operating costs however increase the material cost.

Hence, ideally the cost optimum process would be by combining the best of each process, which is autoclave prepreg, cured using oven curing process. Such analogous process does exist, however are limited to repairing work on a defect aircraft and have not been done commercially(Choi and Jang, 2010). However, with the absence of elevated external pressure, void dissolution would still be a problem. Furthermore, expansion of internal core pressure per unit cell will put a strain on the skin-core interface bonding and possibly deteriorates the overall quality of sandwich composite.

There are a wide array of researches on factors that effects and how to improve the integrity of sandwich structure, particularly on skin-core interfacial adhesion and void formation within structure. It was reported that, individual step of sandwich processing parameters have highly influenced and effected the product quality of sandwich composite. Nevertheless, very little to none have conducted research on the effects of processing parameters towards the quality of autoclave prepreg cured in an oven curing

From the preceding studies, it was reported that two processing parameters exhibited positive improvement on the sandwich skin-core interfacial strength while reducing void formation. They were prolong debulking and bagging configurations; including resin film types and edge breather (Tavares et al., 2010b, Tavares et al., 2010a, Kratz and Hubert, 2011, Kratz and Hubert, 2013). The voids content mostly were diagnosed as large and small. However, the voids reported were focused mainly on those that formed on the skin and rarely on those that formed within the skin-core interface. Be that as it may, all of the processing parameters prominent effect on sandwich composite quality were again mostly on oven cure process with OOA prepreg. Hence there is a need to investigate these said processing parameters effect on the quality of sandwich composite manufactured using cost optimum method of oven curing with conventional autoclave prepreg material.

1.4 Objectives

The general goal of this research is to investigate the effects of oven-curing processing parameters towards qualities of sandwich composite which are void formation and skin-core interface bonding properties. The sandwich composite are constructed using autoclave prepreg as sandwich skin material and cured using oven curing process. The objectives include in this research were as following:

1) To investigate the influence of standard industrial debulking process on Internal Core Pressure (ICP) prior to curing.

2) To characterise the effects of processing parameters towards quantity of Resin Mass Loss and quality of resin fillet area

3) To analyze the relation between resin fillet formation with sandwich composite skin-core bonding strength.