Faculty of Manufacturing Engineering

OPTIMIZATION OF SECONDARY BONDING IN LAYUP PROCESS BASED ON SIX SIGMA METHOD

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I declare that this thesis entitled "Optimization of Secondary Bonding in Layup Process Based on Six Sigma Method" 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.

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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 Manufacturing Engineering.

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DEDICATION

To my beloved late mother, late father and my sisters

ABSTRACT

Composite manufacturing company is a company that produces parts for aeroplane which is made up of composite. Composite is the combination of more than one material to produce a strong part. One of the main problem of this part producing in the composite manufacturing company is recovering the panels once the panel have been scrapped. Besides that, this part have 6 days of lead time or manufacturing time for the parts. The top defect for this part is disbond. Disbond is a mismatching bonding of two parts to have one mutual part. The objectives of this study are to investigate the root cause for disbond defect in composite part by using six sigma analysis, to propose the solution for disbond defect in composite part, and to validate the effectiveness of the proposed solution for current production. In order to find the robust solution, six sigma analysis have been done.The six sigma analysis have five stages which are defined, measured, analyzed, improved and control phase. The proposed solutions can be identified in the analysed phase. The effectiveness of the solution can be defined in the improve phase. Not enough adhesive is the major root cause for disbond. The prefitting process require to define the number of adhesive added to the panel for bonding process. However, the method to define the number of adhesive is too subjective and have been discussed further in this study.

ABSTRAK

Syarikat pembuatan komposit adalah sebuah syarikat yang menghasilkan bahagian-bahagian untuk kapal terbang yang terdiri daripada komposit. Komposit adalah gabungan lebih daripada satu bahan untuk menghasilkan bahagian yang kuat. Salah satu masalah utama bahagian ini yang menghasilkan dalam syarikat pembuatan komposit adalah memulihkan panel apabila panel telah dibatalkan. Selain itu,syarikat ini memerlukan masa 6 hari waktu pembuatan untuk menyiapkan bahagian. Kecacatan teratas untuk bahagian ini adalah *disbond*. *Disbond* adalah ikatan yang tidak sepadan dengan dua bahagian untuk mempunyai satu sama lain. Objektif kajian ini adalah untuk mengkaji penyebab utama kecacatan yang disbond dalam bahagian komposit dengan menggunakan enam analisis sigma, mencadangkan penyelesaian untuk kecacatan disbond dalam bahagian komposit, dan mengesahkan keberkesanan penyelesaian yang dicadangkan untuk pengeluaran semasa. Untuk mencari penyelesaian yang mantap, enam analisis sigma telah dilakukan. Enam analisis sigma mempunyai lima tahap iaitu mentakrifkan, mengukur, meanalisis, membaiki dan fasa mengawal. Penyelesaian yang dicadangkan dapat dikenal pasti dalam fasa meanalisis. Keberkesanan penyelesaian boleh ditakrifkan dalam fasa membaiki. *Adhesive* tidak mencukupi adalah punca utama penyebabnya. Proses prefitting diperlukan untuk menentukan jumlah pelekat yang ditambahkan ke panel untuk proses *bonding*. Walau bagaimanapun, kaedah untuk menentukan bilangan pelekat terlalu subjektif dan telah dibincangkan lebih lanjut dalam kajian ini.

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My appreciation also goes to my family who has been so tolerant and supports me all these years. Thanks for their encouragement, love and emotional supports that they had given to me. Nevertheless, my great appreciation dedicated to my colleague and those whom involve directly or indirectly with this project. Thank You.

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A – Analyse

C – Control

D – Define

DET – Detection

F – Flange

FMEA – Failure Mode and Effect Analysis

I – Improve

IPA – Isopropyl Alcohol

M – Measure

NDT – Nondestructive Tesing

QC – Quality Control

RPN – Risk Priority Number

SEV – Severity

S1 – Specimen 1

S2 – Specimen 2

TPS – Toyota Production System

UV – Ultrasonic Violet

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CHAPTER 1

INTRODUCTION

1.1 Background

Over past 10 years ago, lean manufacturing have been introduced as one of the source of productivity improvement and cost reduction on manufacturing. From Liker and Wu (2000), lean is a philosophy of manufacturing that concentrates on supplying the highest-quality product at lowest cost and on time. This is also applying as well as in the composite manufacturing company.

Composite manufacturing company produces part for the airplane that made with composite. Composite have been choose to be the component of the airplane because of its strength and weight. An airplane needs a very good strength and light weight structure. Composite manufacturing company produces part from any models such as Airbus and Boeing. The processes to produce this part are from receiving, kitting, layup, curing, non-destructive testing, CNC (computer numerical control) , mechanical assembly, secondary bonding and final inspection.

Adhesive have been used to combine two materials together. In this part, the secondary bonding has been chosen to combine the composite. Secondary bonding is joining together by the process of adhesive bonding, two or more pre-cured composite parts, during which the only chemical or thermal reaction occurring is the curing the adhesive.

The main problem of the composite manufacturing company is having the defect that cannot be rework. This problem will affect the delivery part to be delivered in time.

1.2 Problem Statement

Defect is one of the problems in Composite Manufacturing Company. This is because the processing time involved in producing the complete one shipset of the composite 60 days. The program has difficulties to recover parts if the planned delivery part failed at any stage in production floor. Figure 1.1 shows that the most affected is from disbond defect. The disbond defect is the highest in the pareto chart because of the defect have to be scrapped even the defect is too small.

Therefore, composite manufacturing company has to delay the shipment to recover this defect. Once the parts have been scrapped, the production has to produce the new one starting from the raw material. Besides that, company has to bear the cost of transportation once the delivery has failed. In addition, company also has to pay the penalty because of the failed product delivery. This is one of the pressures that need to overcome in order to meet the dateline.

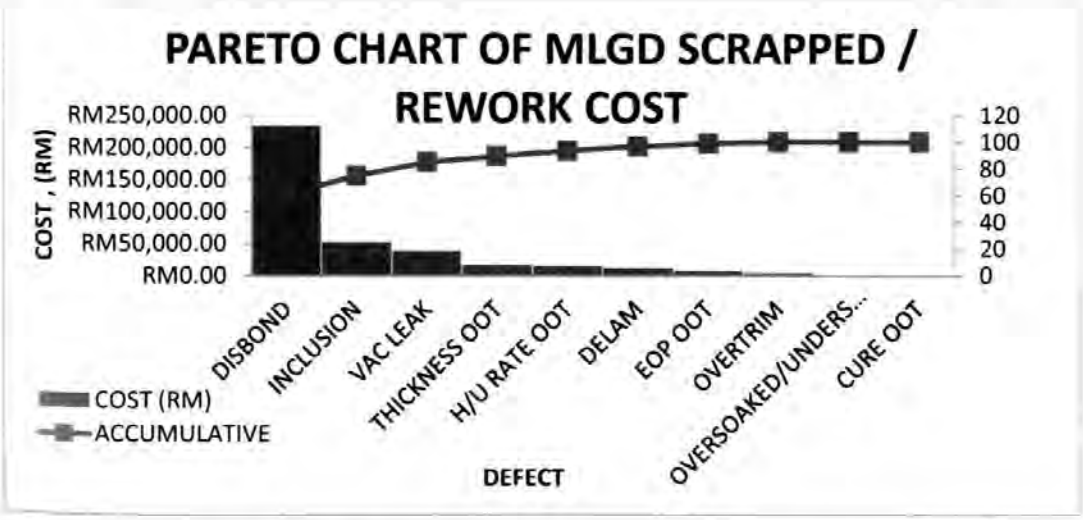


Figure 1.1: Pareto chart of scrapped or rework cost for 2016/2017

Source: Composite Manufacturing Company

Disbond defects can occur between skin to adhesive interface resulting from poor bonding of the skin to adhesive bonded as shown in Figure 1.2. This defect causes the parts to be scrapped and cannot be rework. It is supposed to be no gap between the bonding line and carbon panel. The panel will go into secondary bonding process flow which is the carbon panel need to be cured separately then, it is bonded. Both of the panels need to be clean of any defects in order to bond. Therefore, the panels need to undergo CNC (computer numerical control) process to cut the edges and NDT (non-destructive testing) process to make sure that there is no defect on the panel.

Six Sigma is a disciplined, data-driven approach and methodology for eliminating defects. This method is driving toward six standard deviations between the mean and the nearest specification limit in any process. The six sigma increase in performance and decrease in process variation to lead to defect reduction and improvements in profits, and quality of products.

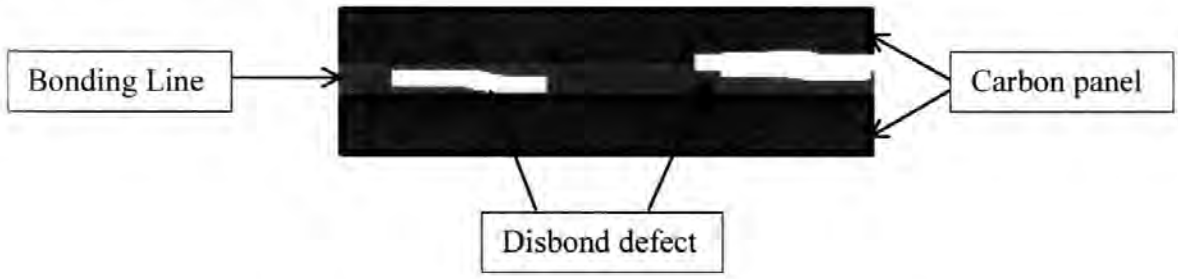


Figure 1.2: Schematic diagram for disbond defect

1.3 Objectives

The objectives of this study are:

i. To investigate the root cause for disbond defect in composite part based on Six Sigma analysis

ii. To propose the solution for disbond defect in composite part

iii. To validate the effectiveness of the proposed solution for the current production

1.4 Scope of the study

To achieve the objective of this study, there are some scope that must be had. This study is only for disbond defect for the composite manufacturing company. It is concentrated on the secondary bonding process only. The method to identify the defect is by using six sigma analysis and validate the solution in the process. The six sigma analysis will be identified the major root cause of the disbond defect.

After the major root causes have been identified, the robust solutions from the defect also need to be identified so that the defect can be reduced or eliminated. The proposed solution can be identified based on analyzed phase on six sigma analysis.

The proposed solutions must be validated on the effectiveness for the current solution. The validation must be done because to ensure the proposed solution is robust enough to the defect. This is also to ensure that no more repeated defect occur.

1.5 Significance of the study

This study will be significant endeavor for the quality of the composite parts. It will be impact the decreasing of the major defect of the composite parts in composite manufacturing company. Besides that, the delivery of this part can be achieved and company will not have to pay extra charged for the manufacturing of this part. With the decreasing of the waste from this composite part, the lean management has been applied on this product.

As the past studies on the secondary bonding process, Markatos (2015) stated that the types of adhesive failure are substrate, adhesive and cohesive failure. There are many others factor for disbond to be happened but there is no the solid justification for this defect. By implementing this study, the disbond defect can be eliminated or reducing. Other than that, the self-confidence can be increasing by inspiring creative ideas in daily

work for more proactive employment and cultivate teamwork in problem solving activities. This is also created a positive impression of the project as it can produce creative and innovations employees while giving the good impact with the company. It also can reduce the defects in the product as well as the customer satisfaction.

CHAPTER 2

LITERITURE REVIEW

2.1 Composite

Mohan (2010) states that composite materials are made from two or more than two materials with considerably differ in physical and chemical properties, that when combined, make a material with appearances different from the individual components. Composites comprise strong load carrying material is known as reinforcement and weaker materials is known as matrix. Reinforcement provides stiffness and strength which helps to support structural load.

Composite have been used widely in many application such as aircraft industry, bicycle, composite tooth, pedestrian bridge, automotive, construction, corrosion-resistant equipment, electrical and marine.

Nayak (2014) claimed that the composites have offer features and disadvantages. The features are:

i. Light weight based on high specific strength and stiffness
ii. Fatigue and corrosion resistance
iii. Capable for high degree in the directional strength and stiffness
iv. Capable to mould large complex shapes in minimum cycle time
v. Able to maintain dimensional and alignment stability in space environment
vi. Low dielectric loss in radar transparency
vii. Low radar cross-section

The disadvantages are:

i. Poor resistance to out of plane tensile loads
ii. Susceptibility to impact damage and strong possibility of internal damage going unnoticed
iii. Moisture absorption and consequent degradation of high temperature
iv. A lot of possible defects and various of material properties

2.2 Adhesive Bonding

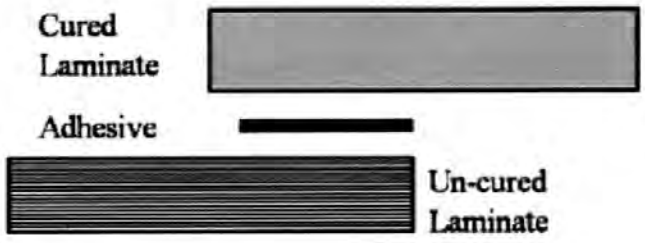
Based on Davis and Tomblin (2007), adhesive bonding of structures have some advantages rather than conventional fastening systems. The bonded from adhesive becomes more fatigue resistant compared to mechanical fastened because of the stress concentrations occur at fasteners. The main advantage of adhesive bonds, it have been designed to be stronger than ultimate strength of any metals that commonly used for aircraft manufacturing. The disadvantage of adhesive bonded joint is a single fastener and there is no laying-off unless alternative load paths are added.

Based on Budhe et al. (2017), the performance of composite bonded joint have been considered into main parameters such as surface preparation, joint configuration, material parameters, geometrical parameters, failure mode etc.

2.2.1 Manufacturing Bonding Process

In Markatos et al. (2013) stated that the manufacturing bonding process is one of the factors that contribute into the failure in bonding process. The main manufacturing bonding processes are co-curing, co-bonding and secondary bonding method. The schematic of these can be seen on the Figure 2.1.

a) Co-bonding



b) Co-curing

c) Secondary bonding

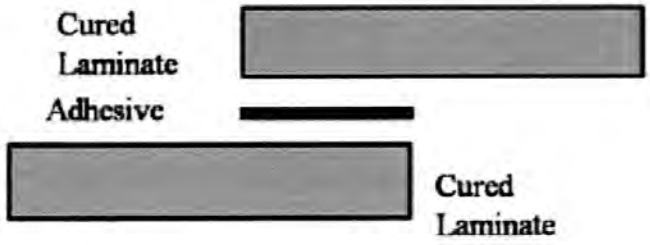


Figure 2.1: Schematic diagram for adhesive manufacturing processes (Budhe et al., 2017)

The co-bonding process is the process which only one adherend is cured with adhesive. Co-curing process have both parts not cured and bond with adhesive. While the secondary bonding is the adhesive is in between two pre-cured panels or substrate. There are some reasons of the manufacturers to choose the process for manufacturing bonding parts. As per stated in Budhe et al. (2017), the co-curing or co-bonding is usually preferred rather than the secondary bonding because of the manufacturing time. It does not required

many curing cycles and it also have common repair of composite structures. On the other hand, because of complex and large structures, the secondary bonding is the more preferred.

In the Mohan et al. (2014 & 2015) research, the co-cured bonded joints have lower strength than the secondary bonding. These facts have been agreed in Song et al. (2010). The parameters during bonding process are the most important thing for bonding. Moisture content or moisture trapped in the panels can be the big influence for the bonding panels. Besides that, the curing temperature and the selection of adhesive material can also give contribution to the bonding strength.

2.2.2 Secondary Bonding

Secondary bonding is process in the joining of two or more pre-cured composites parts which only use chemical or thermal reaction. It requires careful preparation for the previously cured substrate at the bonding surface area. It is usually required uniform clamping between the parts during processing. There are two main methods for the adhesive which are mechanical interlocking and chemical interaction. Mechanical interlocking is the proportion of the surface which is very smooth and no opportunity for the trapped air through the surface (Baldan, 2012 cited in Waugh, 2016). On the other hand, research carried out by Pocius (2007 cited in Waugh, 2016) the chemical interaction or chemical bonding is dominated by the Van der Waals forces interacting between molecules.

2.2.3 Surface Preparation

Surface preparation is the most important process for secondary bonding process and will give the quality impact to the bonded joint. Many of the researchers states that by