

**CLOSED-FORM SOLUTIONS AND STRESS ANALYSIS OF
STAINLESS STEEL/ALUMINUM HYBRID JOINT**

NUR ATHIRAH BT MAT NAWI

UNIVERSITI MALAYSIA PERLIS

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ANALYSIS OF STAINLESS STEEL/ALUMINUM
HYBRID JOINT**

by

**NUR ATHIRAH BT MAT NAWI
(1331410948)**

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TABLE OF CONTENTS

	PAGE
DECLARATION OF THESIS	i
ACKNOWLEDGEMENT	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	vii
LIST OF FIGURES	viii
LIST OF ABBREVIATIONS	xiii
LIST OF SYMBOLS	xiv
ABTRAK	xv
ABSTRACT	xvi
CHAPTER 1 INTRODUCTION	
1.1 Project Background	1
1.2 Problem Statements	4
1.3 Objectives	4
1.4 Scope	5
1.5 Significance of Study	6
1.6 Thesis Outline	7

CHAPTER 2 LITERATURE REVIEW

2.1	Introduction	8
2.2	Bonding Strength in Structural Adhesive Bonded Joint	15
2.3	Stress Analysis of Adhesively-Bonded lap Joints	16
2.4	Quasi-Static Strength and Failure Life of Hybrid (Bonded/Bolted) Composite Single Lap Joint	18
2.5	Adhesive Joining of Aluminum AA6082: The Effect of Resin and Surface	23
2.6	The Strength of Adhesively Bonded T-Joints	27
2.7	Analytical One-Dimensional Models of a Single-Lap Joint	28
2.7.1	Analytical Model for Bonded Joints	28
2.7.2	Analytical Model for Stainless Steel/Aluminum Hybrid Joints	30

CHAPTER 3 RESEARCH METHODOLOGY

3.1	Introduction	34
3.2	Flow Chart of Research	35
3.3	Modeling of Adhesive Joint	36
3.4	Preparation for Further Processing into ANSYS	39
3.4.1	Material for Joining Parts	39
3.4.2	Import Part into ANSYS	40
3.4.3	Define Contact Pairs and Meshing	41
3.4.4	Loads and Constraints	45
3.4.5	Apply Path to Find Stress Distribution	46
3.5	Preparation for Further Processing into Experimental	48
3.5.1	Stainless Steel (304) and Aluminum Alloy (A7075) Preparation	48
3.5.2	Adhesive	49

3.5.3	Adhesive Preparation	50
3.5.4	Installation of Huck bolt	52
3.5.5	Specimen for Hybrid Adhesive Joint	53
3.5.6	Testing Method	56
3.6	Analytical One-Dimensional Models of Stainless Steel/Aluminum Hybrid Joint	57
3.6.1	Analytical Model for Bonded Joint, Bolted Joint and Hybrid Joints	58
CHAPTER 4 RESULT AND DISCUSSION		
4.1	Effect of Adhesive Thickness	61
4.1.1	Effect in Meshing using Different Element Size	61
4.1.2	Von Mises stress for Distribution	63
4.1.3	Deformation	67
4.1.4	Linearized Equivalent Stress	70
4.1.5	Maximum von Mises stress	74
4.2	Comparison Between Experimental and FE Analysis	80
4.2.1	Adhesive Joints	80
4.2.2	Huck bolt Joints	81
4.2.3	Stainless Steel/Aluminum Hybrid Joint	83
4.3	Analytical Model for Stainless Steel/Aluminum Hybrid Joint	84
4.4	Comparison Between FE Simulation and Analytical Model for Stainless Steel/Aluminum Hybrid Joint	88

CHAPTER 5 CONCLUSION	
5.1 Conclusions	90
5.6 Recommendations for Future Work	91
REFERENCES	92
APPENDICES	
APPENDIX A	97
APPENDIX B	98
APPENDIX C	100
APPENDIX D	106
LIST OF PUBLICATIONS	110

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LIST OF TABLE

NO.		PAGE
2.1	Test specimen configuration	19
3.1	Mechanical properties of materials	36
3.2	Information about araldite	50
3.3	The properties of Huck C6L LockBolt and Collar	53
3.4	Specification of Shimadzu Autograph AG-IS (2002).	57
4.1	Adhesive thickness and maximum von Mises stress for stainless steel/aluminum hybrid joint	75
4.2	Geometric and mechanical parameters used	85

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LIST OF FIGURES

NO.		PAGE
1.1	Stresses in single lap joint	3
2.1	Electric meshing of bolted joint	10
2.2	Behavior of a fastener	10
2.3	Deformations in loaded single lap joints with elastic adherents	12
2.4	Shear lag model	12
2.5	Volkersen's adhesive shear stress distribution	13
2.6	Experimental setup for bonded and hybrid composite joints.	20
2.7	Polyurethane adhesive thickness, $t = 1.6\text{mm}$	21
2.8	Polyurethane adhesive thickness, $t = 3.2\text{mm}$	22
2.9	Epoxy adhesive thickness, $t = 3.2\text{ mm}$	23
2.10	Example of a space frame construction	25
2.11	Schematic diagram of T-joint test. (All dimensions in mm).	27
3.1	Flow chart of the project	35
3.2	Dimension of stainless steel (304) and aluminum (A7075)	36
3.3	Dimension of adhesive (0.4 mm thickness)	37
3.4	Dimension of Huck bolt	37
3.5	(a) Stainless steel/aluminum with Huck bolt (b) Stainless steel/ aluminum with adhesive (c) Stainless steel/aluminum hybrid joint	38
3.6	(a) Stainless steel/aluminum with Huck bolt (b) Stainless steel/ aluminum with adhesive (c) Stainless steel/aluminum hybrid joint	40
3.7	(a) Meshing element 0.5 mm (b) Detail for meshing element 0.5 mm	42
3.8	(a) Meshing element 1.0 mm (b) Detail for meshing element 1.0 mm	43

3.9	(a) Meshing element 1.5 mm (b) Detail for meshing element 1.5 mm	44
3.10	Sample load and constraints of (a) Stainless steel/aluminum with Huck bolt (b) Stainless steel/aluminum with adhesive (c) Stainless steel/ aluminum hybrid joint	45
3.11	Process to insert construction geometry	46
3.12	Paths defined in stainless steel/ aluminum hybrid joint (a) Path A (b) Path B (c) Path C	47
3.13	Specimen of aluminium (A7075)	48
3.14	Specimen of stainless steel (304)	49
3.15	Araldite standard	49
3.16	Electronic weighting scale	51
3.17	Mixing the resin and hardener	51
3.18	Adhesive applied onto bottom specimen	51
3.19	Top specimen placed on top of bottom specimen	52
3.20	Huck C6L Lock Bolt	52
3.21	Specimen drilled with 6.5 mm hole	54
3.22	The attachment of Huck C6L Lock Bolt and the collar to the Specimen	54
3.23	Finalising Huck C6L Lock Bolt using installation tool	55
3.24	Completed joint	55
3.25	Tensile test Shimadzu AG-IS (2002)	56
3.26	Specimen test (Before)	58
3.27	Specimen test (After)	58
3.28	Parameter for one-dimensional models of stainless steel/aluminum. hybrid joint	59
3.29	Bonded adhesive joint with overlap length 25 mm	60
3.30	Bolted adhesive joint with overlap length 25 mm	60

3.31	Hybrid joint with overlap length 25 mm	61
4.1	Meshing using element size 0.5 mm for stainless steel/aluminum hybrid joint with adhesive thickness 0.4 mm	62
4.2	Meshing using element size 1.0 mm for stainless steel/aluminium hybrid joint with adhesive thickness 0.4 mm	62
4.3	Meshing using element size 1.5 mm for stainless steel/aluminium hybrid joint with adhesive thickness 0.4 mm	62
4.4	Effect of adhesive thickness to maximum von Mises stress using different size element	63
4.5	Von Mises stress for stainless steel/aluminum hybrid joint with adhesive thickness 2.0 mm	64
4.6	Von Mises stress for stainless steel/aluminum hybrid joint with adhesive thickness 1.6 mm	65
4.7	Von Mises stress for stainless steel/aluminum hybrid joint with adhesive thickness 1.2 mm	65
4.8	Von Mises stress for stainless steel/aluminum hybrid joint with adhesive thickness 0.8 mm	66
4.9	Von Mises stress for stainless steel/aluminum hybrid joint with adhesive thickness 0.4 mm	66
4.10	Total deformation for stainless steel /aluminum hybrid joint with adhesive thickness 2.0 mm	67
4.11	Total deformation for stainless steel /aluminum hybrid joint with adhesive thickness 1.6 mm	68
4.12	Total deformation for stainless steel /aluminum hybrid joint with adhesive thickness 1.2 mm	68
4.13	Total deformation for stainless steel /aluminum hybrid joint with adhesive thickness 0.8 mm	69

4.14	Total deformation for stainless steel /aluminum hybrid joint with adhesive thickness 0.4 mm	69
4.15	Path in stainless steel/aluminum hybrid joint	71
4.16	Linearized equivalent stress for stainless steel/ aluminum hybrid joint with adhesive thickness 2.0 mm	72
4.17	Linearized equivalent stress for stainless steel/ aluminum hybrid joint with adhesive thickness 1.6 mm	72
4.18	Linearized equivalent stress for stainless steel/ aluminum hybrid joint with adhesive thickness 1.2 mm	72
4.19	Linearized equivalent stress for stainless steel/ aluminum hybrid joint with adhesive thickness 0.8 mm	73
4.20	Linearized equivalent stress for stainless steel/ aluminum hybrid joint with adhesive thickness 0.4 mm	73
4.21	Effect of adhesive thickness to maximum von Mises stress	75
4.22	Maximum von Mises stress versus total deformation	76
4.23	Stress distribution on stainless steel/aluminium hybrid joints at center of perforated plated (a) Path A (b) Graph stress distribution for thickness 2 mm, 1.6 mm, 1.2 mm, 0.8 mm and 0.4 mm	77
4.24	Stress distribution on stainless steel/aluminium hybrid joints at center of perforated plated (a) Path B (b) Graph stress distribution for thickness 2 mm, 1.6 mm, 1.2 mm, 0.8 mm and 0.4 mm.	78
4.25	Stress distribution on stainless steel/aluminium hybrid joints at center of perforated plated. (a) Path C (b) Graph stress distribution for thickness 2 mm, 1.6 mm, 1.2 mm, 0.8 mm and 0.4 mm	79
4.26	Adhesive joint	81
4.27	Force against displacement for adhesive joint	82
4.28	Huck bolt joint	83

4.29	Force against displacement for Huck bolt joint	82
4.30	Stainless steel/aluminium hybrid joint	83
4.31	Force against displacement for stainless steel/ aluminum hybrid joint	84
4.32	Load transfer ($b=1\text{mm}$, $C_u=40000\text{ N/mm}$)	86
4.33	Load transfer as a function of C_u ($b=1\text{mm}$)	88
4.34	Analytical model for stainless steel/aluminum hybrid joint by using 0.4 mm, 0.8mm, 1.2 mm, 1.6 mm and 2.0 mm.	89
4.35	Comparison between FE simulation and analytical model for stainless steel/aluminum hybrid joint	90

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
UTM	Universal testing machine
PE A	Orthophtalic polyester resins
PE B	Orthophtalic polyester resins
VE I	Vinylester resin
EPO	Epoxy system
ANSYS	engineering simulation software (computer-aided engineering)
FE	Finite element
FEM	Finite element method
FEA	Finite element analysis

LIST OF SYMBOLS

j	Material been used (aluminum/stainless steel)
$E^{(j)}$	Young modulus of the adherent j in MPa
G	Coulomb modulus of the adhesive in MPa
$u_i^{(j)}$	Longitudinal displacement in mm of the adherent j in the bay i
b	Transversal pitch in mm
d_i	Abscissa of the fastener i (d : edge distance in mm; s : longitudinal pitch in mm)
E	Thickness of the adhesive in mm
$e^{(j)}$	Thickness of the adherent j
L	Length of the lap mm
L_g	Length of the left bar not bonded in mm
L_d	Length of the right bar not bonded in mm
X_p	Length of the plastic region in mm
T_p	Plastic adhesive shear stress in MPa
N	Normal force in N
T	Adhesive shear stress in MPa

Peryelesaian Tertutup dan Analisis Tegasan untuk Gabungan Hibrid Keluli Tahan Karat/ Aluminium

ABSTRAK

Gabungan hibrid ialah gabungan antara ikatan perekat dan juga pengikat mekanikal yang mampu untuk menggabungkan kelebihan kedua-dua jenis gabungan. Hari ini, gabungan hibrid menarik untuk digunakan dalam aplikasi automotif kerana teknik ini boleh menawarkan banyak faedah semasa pembuatan. 3 mm plat nipis aluminium dan keluli tahan karat digunakan sebagai bahan merekat dan perekat yang digunakan adalah berprestasi tinggi iaitu perekat araldite. Penyelidikan ini mempertimbangkan keluli tahan karat/aluminium hibrid yang akan diuji dalam dua cara. Cara pertama menggunakan perisian ANSYS dimana ia telah digunakan untuk berdepan dengan tegangan analisis hibrid tidak serupa menggunakan kaedah elemen hingga. Hibrid tidak serupa telah direka dan mempunyai lima ketebalan yang berlainan iaitu 0.4 mm, 0.8 mm, 1.2 mm, 1.6 mm dan 2.0 mm. Kesan ketebalan setiap perekat dianalisis menggunakan ANSYS. Berbagai ketebalan perekat memberikan nilai yang berbeda untuk tegasan maksimum von Mises. Hal ini ditemukan bahawa hasil ketebalan yang lebih besar menyebabkan tegasan maksimum yang lebih tinggi. Selain itu, berbagai ketebalan perekat juga menghasilkan nilai yang berbeda ubah bentuk. Hal ini menunjukkan bahawa lebih ubah bentuk terjadi ketika ketebalan perekat meningkat. Analisis ini membuktikan bahawa peningkatan ketebalan perekat mengurangi kekuatan gabungan, terutama kerana agihan tegasan meningkat pada permukaan perekat. Sebelum melanjutkan ke pendekatan kedua, perbandingan antara eksperimen dan ANSYS telah dilakukan. Tujuan perbandingan ini adalah untuk membuktikan bahwa analisis ANSYS mirip dengan eksperimen dan hasilnya dapat digunakan. Pendekatan kedua adalah untuk merumuskan persamaan baru menggunakan perisian MATLAB untuk analisis agihan tegasan ricih tegangan geser sepanjang garis ikatan di bawah pengaruh nisbah ketebalan bahan merekat dan nisbah modulus Young. Solusinya disusun berdasarkan analisis Paroissien Eric. Kekuatan dalam sendi dapat dicapai dengan nisbah yang sesuai ketebalan dan modulus Young dari bahan merekat. Hasil dari kedua cara ANSYS dan model analitik dibandingkan dan hasilnya adalah sama, yang berarti bahwa model analitik ini dapat digunakan setidaknya untuk konfigurasi yang dipertimbangkan dalam penelitian ini.

Closed-Form Solutions and Stress Analysis of Stainless Steel/Aluminum Hybrid

ABSTRACT

Hybrid joints are a combination of adhesive bonding and mechanical fastening that are able to combine the advantages of both joint types. Today, hybrid joining is attractive in automotive applications as the technique can offer various benefits during manufacturing. A 3 mm thin plate of Aluminium A7075 and stainless steel 304 were used as the adherend material for experimental test and the adhesive used was high performance Araldite Epoxy adhesive. This research examines stainless steel/aluminium hybrid joints to be tested in two ways. First is by using ANSYS software application where it was employed to deal with stress analysis of the adhesive bonding of hybrid dissimilar joints using the finite element method. Hybrid dissimilar joint specimens were fabricated having five bond thicknesses; t (i.e., 0.4 mm, 0.8 mm, 1.2 mm, 1.6 mm and 2.0 mm). The effect of bond thickness was investigated by using the commercial finite element package in ANSYS. Various thicknesses of adhesive give different values of maximum von Mises stress. It is found that greater thickness results in higher maximum stress. Moreover, various thicknesses of adhesive also result in different values of deformation. This shows that more deformation occurs when the thickness of adhesive is increased. This analysis proves that increasing adhesive thickness reduces the joint strength, mainly because stress distribution is increased on adhesive surfaces. Before proceed to second approach, comparison between experiment and ANSYS was done. The purpose for this comparison is to prove that ANSYS analysis is similar with experiment and the result can be use. The second approach is to formulate a new equation using MATLAB tools for analysis of shear stress distribution along the bond line under effect of adherend thickness ratio and adherend Young's modulus ratio. The solution is formulated based on the analysis of Paroissien Eric. The least stress intensities in the joint could be achieved with a suitable ratio of thickness and Young's modulus of adherends. Result from both method ANSYS and analytical model were compared and the results were in agreement, which means that the analytical model can be used at least for the configuration considered in this study.

CHAPTER 1

INTRODUCTION

1.1 Project Background

The joining of stainless steel/aluminum is normally accomplished by adhesive bonding, mechanical fastening or a mix of both methods. The blend of adhesive bonding and mechanical fastening is often employed as a safe guard against defects within the adhesive layer that may prompt untimely or calamitous disappointment. Forecast of the joint fatigue life and the susceptibility of the adhesive/interface to environmental attack are additional uncertainties that have resulted in hybrid joint designs applied in practice. Hybrid joining is the combination of two or more joining techniques to produce joints with improved properties additional to those obtained from a single technique. The most common types of hybrid joint are used for joining sheet materials and involve an adhesive in conjunction with a point joint such as a fastener (rivet or threaded device), a clinched joint or a resistance spot weld. The hybrid joining technique is attractive in automotive applications because it offers benefits during part manufacturing. Other examples of hybrid joints include a combination of two different fusion processes (e.g. MIG/MAG augmented laser welding) or a combination of two different types of adhesive (e.g. tape combined with paste). The bolts can be utilized as a way to adjust and attach different structural parts to each other, and give fixation during adhesive cure. Furthermore, hybrid joints can offer improved performance in correlation to adhesive bonded joints during crash loading

where part detachment is frequently undesirable. Moreover, hybrid joints can offer improved performance in examination to adhesive bonded joints during crash loading where part separation is often undesirable. It was recently shown (Kelly, 2006) that hybrid composite single-lap joints can be outlined where the bolt transfers a significant part of the load. The joint geometry and adhesive mechanical properties were observed to be significant parameters governing the load transfer distribution in the joint.

Adhesive bonding was commercially applied in industry due to some advantages such as, high corrosion resistance, high fatigue resistance, crack retardance and good damping. In adhesive bonding, adhesive serves as a medium for a load to transmit from one adherent to another (Kinloch, 1987; Lucic, Stoic, & Kopac, 2006). When transmitting a load, the adhesive layer starts deforming due to shear and tensile stress. However, adhesive bonding can utilize stress more uniformly than other bonding such as welding and dissemination bonding. Stress concentration within the adhesive layer can be modified by changing geometry properties such as overlap length, adherent's thickness and Young's modulus. Therefore, accurate analysis of adhesive bonding is becoming more crucial than ever, since the ability of an adhesive joint to spread a load over a large loading area leads to less stress concentration. There are various types of joints such as butt, lap and strap joints. Designers need to consider many different factors when choosing a suitable type of joint for application.

Single lap joints are the most widely used adhesive joints because they are practical, simple and give good stress distribution over the bonded area. When applying loads to the end of the adherents, the adherents are pulled in the eccentricity of the load

path, which produces a bending moment, causing the joint to rotate. Consequently, the adhesive layer will deform due to shear and peel stress.

Besides, five types of stress can be found in adhesive joints such as shear, peel, compression, tension and cleavage stress. Any combination of these stresses maybe encountered in adhesive bonding applications. In Fig. 1.1, τ_p represents the shear stresses that are caused by moving parts, whereas τ_d represents the shear stresses that are caused by the deformation of the adhesive layer. Both shear stresses are parallel to the bonded area. The stresses perpendicular to the bonded area are tensile stresses caused by bending moments (Lucic et al., 2006). Among these stresses, tensile stresses are the most significant in the deforming adhesive layer and adherent. If the yield strength of an adhesive is greater than the adherent, adherents will fail due to tensile stress.

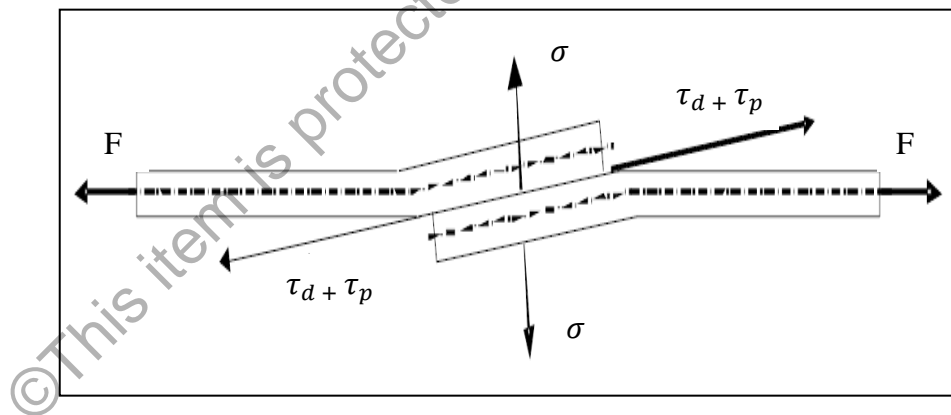


Figure 1.1: Stresses in single lap joint (Lucic et al., 2006).

1.2 Problem Statements

- (a) Many researchers so far only consider using adhesively bonded similar joint to study effect of different adhesives thickness on joint strength and literature for dissimilar material is limited. The study of hybrid dissimilar material is vital as well. Besides, bonding similar and dissimilar adherents can bring different effect to the strength of joint.
- (b) Most automotive industry used adhesive bonding and fastener to assembly part. However the comparison between FEA modeling and experiment results of adhesive, fastener and hybrid joint strength is still lacking.
- (c) Previous researchers using two fasteners and same adherent to form analytical model for hybrid joint.
- (d) There is no analytical model for load transfer within hybrid joint has been developed. Based on studies, no one has compared hybrid joint performance using FEA and analytical model.

1.3 Objectives

The main objectives of this research are listed as follows:

- (a) To investigate the effects of different adhesive thicknesses on joint strength of stainless steel/aluminum hybrid joint.
- (b) To compare the joint strength obtained from finite element analysis (FEA) and experiment for adhesive, huck bolt and hybrid joint.

- (c) To form an analytical model and investigate adhesive load transfer displacement under the effect of different rigidities of the Huck bolt for stainless steel/aluminum hybrid joint.
- (d) To validate load displacement curve between the FEA and the analytical model.

1.4 Scopes

The scope has been defined based on the following points:

- (a) Baseline drawing for stainless steel/aluminum hybrid joint with geometry, dimension and material.
- (b) Conduct static analysis in FEA to simulate different thicknesses of adhesive
- (c) Conduct static analysis in FEA to simulate linearized equivalent stress in three different paths.
- (d) Conduct static analysis in FEA and testing experiment in three different joint (bonded joint, bolted joint and hybrid joint)
- (e) The tensile load and size of the specimen are governed by the mounting on the Universal testing machine (UTM) (Shimadzu Autograph AG-IS, 2002)
- (f) Employ the MATLAB tool to formulate an analytical model for stainless steel/aluminum hybrid joint to investigate adhesive load transfer displacement under the effect of different rigidities of the Huck bolt.

1.5 Significance of Study

The main contribution of this study is to provide additional research such as effects of different adhesive thicknesses on strength of stainless steel/aluminum hybrid joint, difference in strength between an finite element analysis (FEA) and an experiment for adhesive, huck bolt and hybrid joint and to form an analytical model and investigate adhesive load transfer displacement under the effect of different rigidities of the Huck bolt for stainless steel/aluminum hybrid joint. This research is expected to obtain the highest stress concentration which is highest adhesives thickness and the result for analytical model for stainless steel/aluminum hybrid joint. Since stainless steel/aluminum hybrid joint will be more efficient with the application of adhesives, it can be used as the improvement structure for the application in industry, military, automotive or manufacturing. Thus, the main objective are to study about effect adhesive using different material and to form analytical model with different material.

Besides that, the effects of using different thickness for adhesive can be observed in this study. Furthermore, the study on using various kind of different method such as by using FE software ANSYS, MATLAB and comparison with real experiment, will help to provide a design guideline for the engineers, researchers and designers to create the most efficient stainless steel/aluminum hybrid joint. In addition, the results of using different rigidity of Huck bolt also presented in this study.

1.6 Thesis Outline

The first chapter covers the introduction to this study. This chapter additionally presents the overview, objectives, scope, problem statement and expectations of this study. The introduction gives a sure about reason for pursuing this project. Chapter 2 explains the comparative items that are already exist in the literature. It also discusses the advantages and the weaknesses of the most effective items to use. Exactness and precision will be of more concern in this chapter. Chapter 3 presents the methodology that has been carried out to satisfy the research objectives. This chapter provides a detailed explanation of the procedures taken throughout the methodology. In this chapter, all of the tasks are illustrated and the interfacing is presented. Chapter 4 presents an analysis of the results formulated in the previous chapter, followed by a discussion. In this part, the analysis is explained to ensure the project is worth completing. Chapter 5, the last chapter, presents the conclusion to this research. It also presents some recommendations for future work, as well as the limitations encountered in this study.