ADHESIVE JOINT STRENGTH OF DISSIMILAR METAL ADHERENDS BY TAGUCHI METHOD

by

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LIST OF ABBREVIATIONS

AISI	American Iron and Steel Institute
ANOVA	Analysis of variance
AR	As received
ASTM	American Society for Testing and Materials
OA	Orthogonal array
SEM	Scanning electron microscope
SNR	Signal to noise ratio
SQ1	Sequence 1
SQ2	Sequence 2

LIST OF SYMBOLS

A	Bonding surface area
DOF	Degree of freedom allied with the factors
DOF_{TM}	Degree of freedom for Taguchi Method
F	Maximum force in tensile bonding test
m	Average joint strength
m_A	Average joint strength for factor A
m_B	Average joint strength for factor B
m_C	Average joint strength for factor C
MS	Mean squares
n	Total number of response
n_F	Number of factor
n_i	Number of response in factor
n_L	Number of variable
n_S	Number of responses in the factor level combination
R_a	Adherends' surface roughness
SSA_i	Sum of square for i^{th} factor
SSE	Noise sum of square
SST	Total sum of square
T	Sum of all n responses
T_i	Sum of all n_i responses
y_{ij}	Responses j^{th} in i^{th} factor
y	Responses for the given factor level combination
Y_{opt}	Estimated optimum joint strength
σ_{st}^{U}	Tensile joint strength

Kekuatan Ikatan Perekat Bagi Merekat Logam Tak Sama menggunakan Kaedah Taguchi

ABSTRAK

Penyambungan dua jenis logam yang berbeza digunakan secara meluas dalam banyak aplikasi. Banyak usaha telah dilakukan untuk mengkaji teknik penyambungan untuk mencapai kekuatan yang dikehendaki bagi dua logam berbeza termasuklah kimpalan. Walau bagaimanapun, banyak kaedah kimpalan menghadapi kegagalan kritikal kerana terdapat perbezaan dalam pengembangan haba antara logam yang berbeza. Penyelidikan ini berkaitan dengan penyiasatan untuk menyatukan logam yang berbeza iaitu antara keluli tahan karat dan keluli karbon dengan menggunakan teknik sambungan perekat. Ikatan perekat mempunyai kelebihan dan keupayaan untuk menyatukan pelbagai jenis bahan. Tujuan utama kajian ini adalah untuk mengkaji kesan rawatan haba ke atas keluli karbon sederhana (AISI 1045) dan keluli tahan karat (AISI 304) juga kesannya kepada kekuatan ikatan perekat. Pendekatan eksperimen telah dibuat untuk mencapai tujuan penyelidikan dengan mengambil kira faktor-faktor ini; sifat-sifat mekanik bahan yang mahu direkat, rawatan permukaan dan ketebalan perekat. Sifat-sifat mekanik dikawal dengan menggunakan beberapa proses rawatan haba, penyepuhlindapan untuk keluli tahan karat sementara penyepuhlindapan, penormalan, dan pelindapan dilakukan ke atas keluli karbon. Rawatan permukaan dikawal dengan menggunakan kertas las dengan kersik 180, 500, dan 1000. Akhirnya, jig penjajaran digunakan untuk mengawal geometri dan ketebalan perekat iaitu 0.5mm, 1.0mm, dan 1.5mm. Perekat yang digunakan dalam penyiasatan ini adalah Araldite iaitu perekat epoksi yang lambat awet; ia terdiri daripada dua komponen iaitu damar dan pengeras yang dihasilkan oleh Huntsman Corporation dan spesimen dibahagikan kepada tiga kumpulan yang dinamakan sebagai as sepertimana terima (AR), urutan 1 (SQ1) dan urutan 2 (SQ2). Setiap kumpulan mempunyai sembilan keadaan eksperimen yang dijalankan menggunakan kaedah Taguchi. Tiga spesimen disediakan untuk setiap keadaan eksperimen. Sejumlah 81 ujian tegangan pada suhu bilik telah dijalankan di bawah ujian tegangan paksi oleh Mesin Ujian Semesta (UTM). Nisbah isyarat-hingar (SNR) dan varians analisis (ANOVA) digunakan untuk mencari penetapan parameter optimum yang menghasilkan spesimen ikatan perekat sambungan temu dengan kekuatan tegangan tertinggi. Ujian-ujian lain juga turut dilakukan ke atas bahan yang mahu direkatkan iaitu ujian kekasaran permukaan dan pemeriksaan visual untuk mencari hubungan atau sebab yang menyokong keputusan analisis. Berdasarkan keputusan ANOVA bagi kumpulan AR, didapati bahawa sumbangan ketebalan perekat adalah 59.38%, iaitu lebih tinggi berbanding kertas las, 28.76%. Bagi kumpulan SQ1, faktor yang mempengaruhi kekuatan tegangan dalam urutan menurun adalah kertas las, 26.09% diikuti oleh ketebalan perekat dan rawatan haba masing-masing dengan 24.12% dan 12.71%. Sementara itu, faktor utama yang mempengaruhi kekuatan tegangan dalam kumpulan SQ2 ialah ketebalan perekat 67.51%, diikuti dengan kertas las dengan 12.80% dan rawatan haba 11.00%. Hasil analisis membuktikan bahawa rawatan haba mempunyai pengaruh yang sangat kecil ke atas kekuatan sambungan temu perekat antara AISI 1045 dan AISI 304.

Adhesive Joint Strength of Dissimilar Metal Adherends by Taguchi Method

ABSTRACT

The dissimilar metal joints are widely used in many applications. A lot of efforts have been made to study the joining techniques in order to achieve a reliable dissimilar joint for unlike metals including welding. However, dissimilar welding methods is facing critical failure because of the differences in thermal expansion between the different metals. This research is concerned with the investigation of joining dissimilar metal between stainless steel and carbon steel by adhesive joining technique. Adhesive bonding has the advantage and ability to joint different types of material. The main purpose of this study is to investigate the effect of heat treatment on medium carbon steel (AISI 1045) and stainless steel (AISI 304) and its effect on adhesive bonding strength. An experimental approach has been made to attain the research purpose with respects to these factors; adherend mechanical properties, surface treatment and adhesive thickness. The mechanical properties were controlled by using several heat treatment processes, annealing for stainless steel whilst annealing, normalizing, and quenching was done on carbon steel. Surface treatment was controlled by using sandpaper at 180, 500, and 1000 grit. Lastly, an alignment jig was used to control the joint geometry to have an aligned butt-joint specimen and to have a 0.5mm, 1.0mm, and 1.5mm adhesive thickness. The adhesive used in this investigation is Araldite, a slow-setting epoxy adhesive; it consists of two components which are resin and hardener manufactured by Huntsman Corporation and the specimens were divided into three groups which were named as as-received (AR), sequence 1 (SQ1) and sequence 2 (SQ2). Each group has nine numbers of experiments which were carried out by using Taguchi Method. Three specimens were prepared for each experimental condition. A total of 81 tensile tests at room temperature have been carried out under axial tensile test by Universal Testing Machine (UTM). Signal-to-noise ratio (SNR) and analysis of variance (ANOVA) analysis was used to find the optimal parameter setting resulting the highest tensile strength of adhesive bonded butt-joint specimen. Other tests were also done on adherend which are surface roughness and visual examination to find the relation or underlying reason for the analysis results. Based on ANOVA results, it was found that the contribution of adhesive thickness is 59.38%, which is higher than abrasive paper, 28.76% for AR group. For SQ1 group, the factors influencing the tensile strength in descending order are abrasive paper, 26.09% followed by adhesive thickness and heat treatment with 24.12% and 12.71% respectively. While the main factors influencing the tensile strength in SQ2 are adhesive thickness 67.51%, followed by the abrasive paper with 12.80% and then heat treatment 11.00%. This result shows that the heat treatment process have insignificant influence on adhesive butt-joint strength of AISI 1045 and AISI 304.

CHAPTER 1 : INTRODUCTION

1.1 Mechanical joining and adhesive joint

Mechanical joining/bonding is the methods to assemble material to be a mechanical structure where it offers a series of choices for researchers to consider. To obtain a desirable outcome, a trade off exist between cost, performance and impression on the finish product's weight. The joining technique is vital to manufacturing decisions. The urge to find the best joining technique, joining knowledge and approaches were explored by many researchers every day which leads to the study of adhesive bonding technique. Adhesive bonding is becoming one of the popular joining approaches in metal industries since it provides a different solution over other conventional practices such as riveting, welding, bolting and soldering (Borsellino, Bella, & Ruisi, 2009). Adhesive-bonding is a joining process whereby materials are held together by the surface attachment of adhesives as illustrate in Figure 1.1.

Figure 1.1: Illustration of adhesive bonding

A material is required to have four characteristics to perform as an adhesive. First, capable of surface wetting, able to adhere, develop strength after it has been applied, and remain stable. Adhesive bonding offers an advantageous alternative to conventional assembly procedures. It can join dissimilar metal with different thermal expansion. It will lessen the corrosion problem, discoloration and weld worms. It enable lightweight and can join complex structure (Bordes et al., 2009; Seo & Lim, 2005).

1.2 Research background history

The demands to join stainless steels and carbon steels has increased. The joining was attempted for application in power industries, steam generators, hydraulic valves and even in construction industries (Ciupack, Pasternak, Mette, Stammen, & Dilger, 2017; Gaffar, Mudavath, Kumar, & Satyanarayana, 2017; Mishra, Tiwari, & Rajesha, 2014; Saini, Arora, Pandey, & Mehdi, 2014). Growing trend as engineers/researchers across industry lines are always looking to lower production and labor costs and increase quality and consistency of a process.These are when adhesive joint may be the possible alternative for joining the two metals. As of today, the use of adhesive in engineering world is well-established in certain industry.

1.3 Problem statement

Dissimilar metal joint can be complicated and extents a wide-ranging of methodologies, materials and procedures. It is often more difficult than joining the same material. Adhesive bonding has a good spot in present industry. There are also a lot of comprehensive study on adhesive bonding available in literature yet not much study was done on the behaviours of adhesive bonding strength on heat treated metals specifically stainless steel and carbon steel. Consequently, the problem statement for this study is briefly listed below:

i. Dissimilar metal joint between stainless steel and carbon steel is difficult because of the differences in the mechanical and thermal properties.

ii. Adhesive joint processes tend to be labour intensive where a systematic approach need to be applied during the whole research progress.

iii. It is difficult to identify the critical parameter that governs the strength of adhesive joint.

1.4 Objective

This study aimed to lessen the problem in joining stainless steels and carbon steels. Hence, the main purpose is to find possible optimum solution of adhesive joint between those two metals despite difference in mechanical properties. To attain the research purpose, the study is divided into several sub objectives and are listed below:

i. To study the effect of heat treatment on stainless steels and carbon steels in regards of material properties and micristructure and it's relation to adhesive joint strength.

ii. To optimize adhesive joint strength between dissimilar adherends by using systematic approach; Taguchi Method.

iii. To investigate the significance of parameters; abrasive paper, heat treatment, and adhesive thickness by using signal to noise ratio (SNR) and analysis of variance (ANOVA).

1.5 Scope

The scope of this research is to prepare the adhesive bonding specimens with respects to three control factors. Those factors are (i) mechanical properties, (ii) surface treatment, and (iii) joint geometry. The mechanical properties was controlled by using several heat treatment processes, quenching for stainless steel whilst annealing, normalizing, and quenching were done on carbon steel. Surface treatment were controlled by using silicon carbide abrasive paper at 180, 500, and 1000 grit. Lastly, an alignment jig was used to control the joint geometry to have an aligned butt-joint specimen with different adhesive thickness; 0.5mm, 1.0mm, and 1.5mm according to the design of experiments that was carried out by using Taguchi method. The adhesive bonding specimens consisted of adherends that were prepared with accordance to ASTM D2094-00 (ASTM Standard D2094 - 00, 2006).

The adhesive bonding specimens was subjected to tensile test to determine the tensile strength by using universal testing machine (UTM). Results obtained were analysed by using signal-to-noise ratio (SNR) and analysis of variance (ANOVA) method. Characterisation test were carried out in between the specimen preparation up to the completion of tensile test where the surface roughness and visual inspection were done on the adherend. The characterisation results will be incorporated into the further investigation of adhesive bonding strength obtained in the tensile test.

1.6 Thesis organization

This thesis is divided into five chapters. Chapter 1 is the overview of this research where the problem and motivation of the study will be presented. This chapter consisted of several sub-topics that will explain the objective, problem statement, scope of the research, and thesis outline. In the end of this chapter, the reader will be able to briefly understand the general knowledge of the topic and will know what to expect throughout the thesis.

Chapter 2 surveys major outlines of the research. Numbers of previous studies on related topic was collected and summarized in this chapter to bring out the information that will guide the direction of the research. This chapter also helps to characterize the role of a method and tools in its enactment. Besides, it contains comprehensive review that contributes to the design of experiment of the research.

Chapter 3 of the thesis describes the approach undertaken throughout the research. This chapter is strongly affected by the findings in Chapter 2. Every method used was clarified in details including the relevance for the application of particular procedure used thereby, permitting the reader to critically value the validity and dependability for overall study.

Chapter 4 delivers the experimental outcomes including statistical analysis, SNR and ANOVA which were used in this study. The statistical results were then interpreted and its relation to the research problem were discussed. This chapter also presents further discussion on any contradictory results obtained.

Chapter 5 provides the conclusion of the present work by highlighting the research objectives. This chapter also provides general recommendations and implications of the study for future work.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

This chapter consists of several sections that comprises about dissimilar material joining application and current joining problem issues. Substantive information of joining technique were included where the basic knowledge of adhesive joint is introduced, as well as theoretical and methodological contributions to a particular procedure. Besides, this chapter also includes the survey of systematic experiment design.

2.2 Dissimilar metal joint (stainless steels and carbon steels)

Various applications exist in engineering that demands joining dissimilar steel. The joining of stainless steel and carbon steels are widely attempted for application in nuclear applications, power industry, steam generators, construction industry, and small products like hydraulic valves. One of the application can be found in thermal power generation industry is where stainless steels need to be used in the heater area that exposed with high temperatures and under more severe corrosion conditions. While carbon steel can perform sufficiently at areas that operates under certain level of temperature and conditions and may save the total cost of structure (Gaffar et al., 2017; Maurya, Pratap, Kumar, & Rana, 2017; Mishra et al., 2014; Poulose, Sanjeev, Prabakaran, & Rajkumar, 2015)

Stainless to carbon steel joints usually formed by using mechanical fasteners and conventional welding and technique. Ciupack et al., (2017) stated that regardless of much development of conventional joining techniques, these problems still exist; residual stresses for welds also failure at cross section for fasteners. Several studies of joining of two metals have been reported and encountered almost the same difficulties. Mishra et al. (2014) stated that it is tough to join stainless steel to carbon steel by welding due to the carbon precipitation and chromium loss during joining process leads to deteriorate the strength. According to Farren, Dupont, & Noecker (2007), dissimilar metal weld (DMW) cannot solve the problem occurs in most industrial applications Come to assumption, joining of stainless to carbon steels is not an easy task.

2.3 Influence of welding on steel microstructure

High temperature imposed during welding caused the microstructure and mechanical properties of the material being welded changed at the interface region. There are several studies to investigate the microstructural of welded joints of stainless to carbon steels. After being imposed to heat, the microstructure changed depends in the type of welding process and how it was cooled. Based on some literature survey, it was found that these are the possible microstructure appeared at the carbon steel after welding; pearlite, bainite and martensite. As for stainless steel, the microstructure remain as austenite or might have small amount of ferrite.

One of the study was done by Kirik, Ozdemir & Caligulu (2012) where they examined the microstructure reaction of welded AISI 304 L and carbon steel AISI 1040. Their results shows that at the central region of the weld, there was a grain refinement due to the heat input and pressure which lead to the existing of austenite and martensite. The microstructure of AISI 1040 deformed as ferrite+pearlite after welding as shown in Figure 2.1. The microstructure examination was done using Scanning Electron Microscopy (SEM) where AISI 304 L was etched electrolytically in a solution of 50% HNO_3 + 50% of H_2O while AISI1040 was etched in 2ml HNO_3 + 98% ml alcohol solution for the microstructure to appear.

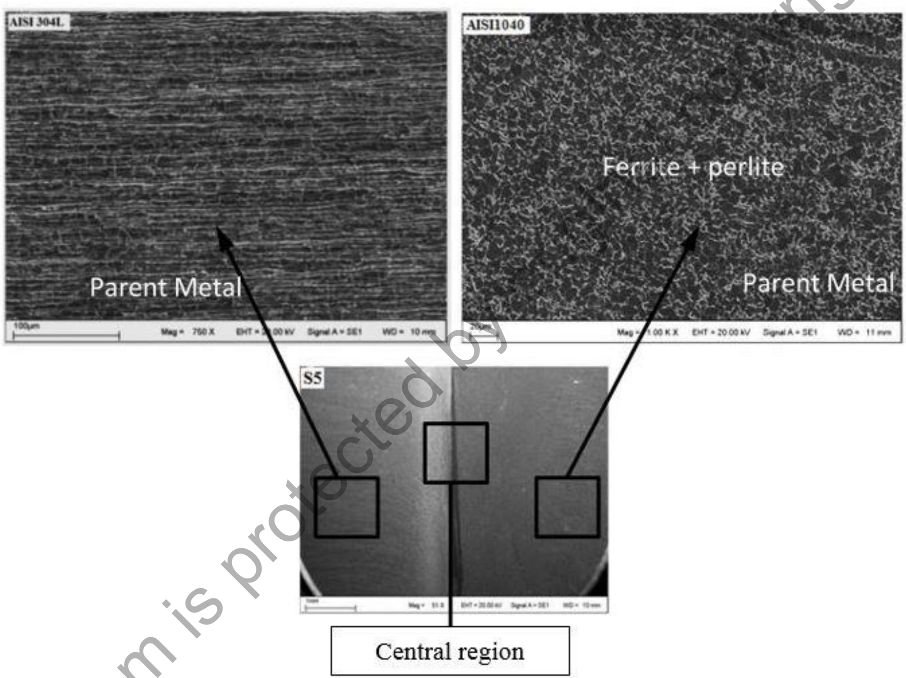

Figure 2.1: SEM photographs taken from the weld zone
Source: (Kirik et al., 2012).

Farren, Dupont, and Noecker (2007) studied on the fabrication on 1085 carbon steel to 316 stainless steel transition joint using direct laser deposition method. The found austenite existed on 316 stainless steel region which is typical. The microstructure was made appear by using 10 % oxalic electrolytic etch. This region was followed by region near the interface between the two steels. The etchant used at this region is 2% nital + sodium metabisulfite. This region is appeared to be