Faculty of Mechanical Engineering

THE PROCESS PARAMETER EFFECTS ON HYBRID STRUCTURE OF DISSIMILAR MATERIALS MADE BY FRICTION STIR WELDING

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THE PROCESS PARAMETER EFFECTS ON HYBRID STRUCTURE OF DISSIMILAR MATERIALS MADE BY FRICTION STIR WELDING

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DECLARATION

I declare that this thesis entitles "The Process Parameter Effects on Hybrid Structure of Dissimilar Materials Made by Friction Stir Welding" 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 the candidature of any other degree.

Signature :.....

Name: :Sadiq Aziz Hussein

Date: :.....

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 Doctor of Philosophy.

Signature : .....

Supervisor Name : Assoc. Prof. Abd Salam bin Md Tahir

Date: : .....

DEDICATION

This thesis work is dedicated to my Parents, Norizana, Noor, Meriam, Fatima, and my big family; you are good examples have taught me to work hard for the things that I aspire to achieve.

ABSTRACT

In order to accommodate the demand for low weight product, significant effort is being directed towards the replacement of steel by Al Alloys for particular structural parts in transport applications. However, it is difficult to find the most suitable joining method due to dissimilarities in the thermal and mechanical properties of the materials in such structures. For example, joining of Al Alloy to steel by fusion welding methods produces deleterious reactions as a result of the associated melting and resolidification processes. Friction stir welding could be a better choice by exploiting its solid-state process behaviour to join such dissimilar materials. The aim of this study is to investigate the process parameters effect on a joint made by friction stir welding for three dissimilar materials. It also aims to produce this joint in low cost manner, and with modification of tools used. Single pass friction stir welding has been used to join three dissimilar metallic alloys of hardened and tempered Al Alloys in butt configuration, to steel in lap configuration. Preliminary investigation and pilot test have been conducted to achieve low-cost welding process and detect the initial levels of the welding process parameters. Few steps have been implemented to attain suitable range of these parameters of both joints. In Al Alloys to steel joining, diffusion and plunging have been investigated for eligibility, matching with low-cost welding process, and attaining robust joint. The design of experiments and analysis of variance have been used to explain the effects of welding parameters on joint strength in this study. Rule of thumb has been established from preliminary investigation to mitigate the high generated forces during the critical stages of the welding process. This preliminary investigation suggests significant experimental steps for the next stage which is welding of dissimilar materials. The pilot investigation succeeds in detecting the initial level of the welding parameters, selection of best technique for the welding of Al Alloys to steel, and arrangement of Al Alloys sheets on the retreating and advancing sides. The final collected data shows that low welding speed (such as 20 mm/min) is important to attain robust Al Alloy to steel joint, while high speed (such as 300 mm/min) produces high tensile strength of Al Alloys joint. Generally, low rotational speed such as 400-900 rpm, will result in poor weld quality, while high rotational speeds, such as 1800 and 2000 rpm, produce consistent range of joint strengths and good weld quality. Extremely high welding (400 mm/min) and rotational ($\geq$ 2000 rpm) speeds will produce weld defects as well. Steel fragments spattered at the weld zone, weld defects, and the mechanical properties of the formed intermetallic layer and its thickness are the influential factors in the Al Alloy to steel joint. Diffusion technique is known to be able to avoid the limitation of pin plunging into steel. Though the strain failure values may be low as compared to the base materials, dissimilar Al Alloys joint efficiency can achieve 85% of the AA6061-T6 base material, while Al Alloys to steel joints can attain approximately 100% of the steel base material. A new tool, multi-adjustable, has been proposed for the future work. The new design accommodates some of the main affected parameters in the targeted structures as suggested by the final results of this study. The use of this tool could further reduce the cost of the friction stir welding process.

ABSTRAK

Untuk memenuhi permintaan terhadap produk yang ringan, pelbagai usaha sedang dijalankan untuk menggunakan Aloi Aluminium (Al Alloy) sebagai ganti kepada besi untuk pembinaan bahagian struktur kenderaan. Walau bagaimanapun, adalah rumit untuk mencari kaedah sambungan yang paling sesuai disebabkan ketidaksamaan kandungan termal dan mekanikal dalam bahan binaan. Sebagai contoh, sambungan Aloi Aluminium dengan besi melalui kaedah kimpalan gabungan akan menghasilkan reaksi kehancuran, akibat proses pencairan dan pemejalan semula. Kimpalan kacau geseran berpotensi sebagai pilihan yang lebih baik, dengan memanipulasi sifat proses pemejalannya untuk sambungan bahan berlainan. Kajian ini bertujuan untuk mengkaji kesan-kesan parameter proses pada sambungan menggunakan kimpalan kacau geseran untuk tiga bahan binaan berlainan. Kajian ini juga bertujuan menghasilkan sambungan yang lebih murah, melalui modifikasi alat yang digunakan. Kimpalan kacau geseran laluan tunggal telah digunakan tiga bahan aloi metalik yang telah dikeras dan ditempa dengan konfigurasi butt, kepada besi dalam konfigurasi pusingan. Kajian awal dan ujian rintis telah dijalankan untuk menghasilkan proses kimpalan yang lebih murah, dan untuk mengesan tahap awal parameter proses kimpalan. Beberapa langkah telah diambil untuk mendapatkan lingkungan parameter untuk kedua-dua sambungan. Dalam sambungan Aloi Aluminium kepada besi, teknik sebaran dan junaman telah dikaji untuk kesesuaian, padanan dengan proses kimpalan murah dan mendapatkan sambungan yang teguh. Rekabentuk eksperimen dan analisis varians telah digunakan untuk menerangkan kesan-kesan parameter kimpalan ke atas kekuatan sambungan. Peraturan ibu jari telah dibentuk dalam kajian awal untuk mengurangkan penghasilan tenaga yang tinggi semasa tahap kritikal proses kimpalan. Kajian awal ini mencadangkan langkah-langkah eksperimen yang signifikan untuk tahap seterusnya, iaitu kimpalan bahan berlainan. Ujian rintis ini mampu mengesan tahap awal parameter kimpalan, memilih teknik terbaik untuk kimpalan Aloi Aluminium kepada besi, dan susunan helaian Aloi Aluminium pada sebelah unduran dan majuan. Data akhir menunjukkan bahawa kelajuan kimpalan yang rendah adalah penting untuk menghasilkan sambungan Aloi Aluminium kepada besi yang teguh, manakala kelajuan tinggi akan menghasilkan kekuatan tegangan sambungan Aloi Aluminium yang tinggi. Pada asasnya, putaran kelajuan rendah, contohnya 400-900 rpm, akan menghasilkan kualiti kimpalan yang rendah, manakala putaran kelajuan tinggi, contohnya 1800-2000rpm, akan menghasilkan lingkungan kekuatan sambungan yang konsisten dan kualiti kimpalan yang baik. Walau bagaimanapun, kelajuan kimpalan dan putaran yang tinggi (400 mm/min, ≥ 2000 rpm) akan mencacatkan kimpalan. Serakan besi dalam zon kimpalan, kecacatan kimpalan, kandungan mekanikal dan tebal lapisan antara metalik adalah faktor yang boleh mempengaruhi sambingan Aloi Aluminium kepada besi. Teknik sebaran diketahui mampu mengelakkan pin daripada terjunam dalam had besi. Walaupun nilai kegagalan tegangan mungkin rendah berbanding bahan asas, sambungan Aloi Aluminium berlainan mampu mencapai keberkesanan 85% bahan asas AA6061-T6, manakala sambungan Aloi Aluminium kepada besi mampu mencapai keberkesanan100% bahan asas besi. Alat boleh

laras yang baru telah disyorkan untuk kajian masa hadapan. Hasil akhir kajian ini mendapati bahawa rekabentuk baru ini mampu mengatasi beberapa parameter yang terjejas dalam struktur yang dikaji. Penggunaan alat ini juga boleh mengurangkan kos proses kimpalan kacau geseran.

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LIST OF ABBREVIATIONS

Abbreviation	Specification
3D	Three dimensional
Al-to-Al	Aluminum to Aluminum
Al-to-steel	Aluminum to steel
ANOVA	Analysis of variance
AS	Advancing side
BC	Boundary condition
BM	Base material
DOE	Design of experiments
DRX	Dynamic recrystallization
DT	Dwell time (s)
EDX	Energy dispersive spectroscopy
FEM	Finite element method
FSBW	Friction stir butt welding
FSLW	Friction stir lap welding
FSP	Friction stir processing
FS weld	Friction stir weld
FSW	Friction stir welding
HAZ	heat affected zone
HV	Hardness (Vickers)
IMC	Intermetallic compound
PLD	Pin plunge depth in the steel plate (mm)
RS	Retreating side

SC	Smoothly cylindrical profile
SD	Shoulder dipping (mm)
SEM	Scanning electron microscopy
SZ or DXZ	Stir zone
TMAZ	Thermomechanical affected zone
TWB	Tailor welded blank
UTS	Ultimate tensile strength (MPa)
WZ	Weld zone
XRD	X-ray diffraction