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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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A STUDY ON DOUBLE FILLET LAP WELDING OF THIN SHEET AZ31B MAGNESIUM ALLOY BY LOW POWER FIBER LASER

MUHAMMAD NAQIUDDIN BIN MAT SALLEH

Thesis submitted in fulfilment of the requirements
for the award of the degree of
Master of Science

Faculty of Mechanical Engineering

UNIVERSITI MALAYSIA PAHANG

JULY 2017

ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincere gratitude to my supervisor, Associate Professor Dr Mahadzir Bin Ishak@Muhammad and my co-supervisor, Dr. Fadhlur Rahman bin Mohd Romlay for his invaluable guidance, ideas, constant encouragement and continuous support in making this research project possible. I am grateful for their consistent support throughout the project with patience and knowledge while allowing me the room to work on my own. I would also like to thank them for the time spent on proofreading and correcting the mistakes in the thesis.

Certainly, not forget the Faculty of Mechanical Engineering, UMP for providing the support and equipment required in the present study. My sincere thanks also go to all my lab mates and members of the technical staffs of Faculty of Mechanical Engineering especially the instructor engineers, Mr Zulkarnain and Mr Azuwar who helped me in many ways especially with the operation of machines and equipment.

Last but not least, I would like to thank my loving parents and my brothers and sister for their continuous support and guidance throughout my master study in Universiti Malaysia Pahang. Without the encouragements from them, I could not possibly afford to pursue this level of study.

ABSTRAK

Tesis ini membentangkan kajian kimpalan laser kepingan nipis AZ31B Magnesium (Mg) aloi menggunakan laser gentian berkuasa rendah. AZ31B dikenali sebagai logam yang lebih ringan berbanding aloi aluminium (Al) dan keluli dengan ketumpatan 1.78 g/cm^3. AZ31B berketebalan nipis digunakan dalam aplikasi automotif, penerbangan dan bahagian peranti elektronik seperti selongsong komputer dan kepingan nipis di dalam telefon pintar. Kimpalan laser berpotensi sebagai kaedah yang baik untuk pengimpalan AZ31B nipis berbanding dengan kimpalan arka dan kimpalan berkeadaan pepejal di dalam menghasilkan hasil kimpal yang kecil. Kimpalan laser gentian berkuasa rendah dipilih dalam penyelidikan ini dan parameter kimpalan dioptimumkan dengan kaedah sambutan permukaan (RSM) menggunakan kaedah reka bentuk Box-Behnken (BBD) untuk mendapatkan keadaan yang paling sesuai bagi mengimpal AZ31B nipis ini. Kaedah kimpalan laser dengan menggunakan sambungan tindih kambi berganda dipilih kerana ia boleh menghasilkan masukan haba yang rendah bersama kuasa yang tinggi pada ketebalan 0.6 mm disebabkan oleh geometri kimpal sambungan tindih kambi di mana alur difokuskan di hujung kepingan atas. Ia dipilih kerana penggunaan laser yang amat berpengaruh terutama di dalam industri pembuatan. Objektif pertama penyelidikan ini adalah untuk mengoptimumkan parameter kimpalan laser untuk mengimpal sambungan tindih kambi berganda terhadap AZ31B. Objektif kedua ialah untuk menyiasat kaitan antara perubahan mikrostruktur pada sifat-sifat mekanikal untuk sambungan ini. Mengikut reka bentuk eksperimen (DOE) yang dihasilkan oleh BBD, 15 sampel telah dikimpal dan kekuatannya diuji menggunakan ujian kekuatan tegangan ricih. Dari sambutan, model matematik dibina selepas pelaksanaan analisis varians (ANOVA). Membincangkan hubungan antara kekuatan ricih dan mikrostruktur, sampel yang dikimpal kemudian dipotong pada keratan rentas kimpalan yang stabil dan telah dipersiapkan untuk pemerhatian makro dan mikrostruktur. Sampel 9 mempunyai kekuatan ketegangan ricih tertinggi iaitu 62.0 MPa dan beban patah ialah 740 N. Satu model matematik dengan persamaan kuadratik telah dihasilkan untuk menghitung kekuatan tegangan ricih. Untuk pengesahan model matematik, peratusan kesilapan bagi semua sampel adalah kurang daripada 8%. Ia menunjukkan kejituan yang tinggi dan telah diterima. Parameters kimpalan kemudian diteruskan untuk dioptimumkan. Parameter yang dioptimumkan adalah; tenaga denyut (EP): 2.2 J; kelajuan kimpalan (WS): 2.0 mm/s; dan sudut penyinaran (AOI): 2.0°. Peratusan kesilapan bagi sampel yang dioptimumkan ialah 0.79 %. Ujian kekerasan Vickers dilakukan pada kawasan kimpalan untuk sampel dengan tertinggi dan sampel yang telah dioptimumkan untuk tujuan perbandingan. Diperhatikan bahawa kebanyakan sampel yang dikimpal mempunyai pemejalan retak di tengah kawasan kimpalan bagi kumai kimpal kedua dan kecacatan ini menyumbang kepada kekuatan tegangan ricih yang lebih rendah berdasarkan makrograf yang telah diperhatikan. Untuk mikrostruktur, bijian yang halus telah terhasil di zon pelakuran (FZ) berbeza daripada FZ berdekatan dengan garisan peralihan yang mana menghasilkan bijian yang kasar dan sederhana. Sampel yang dioptimumkan telah patah di kawasan peralihan pada kepingan atas, manakala sampel 1 patah pada kimpal diebabkan oleh kecacatan retak. Diperhatikan bahawa patah tersebut adalah rapuh. Sampel yang dioptimum mempunyai 80.5 Mpa kekuatan tegangan ricih dengan daya beban 800 N dimana boleh menggantikan Al dan keluli terutama untuk peranti electronic kerana kekuatan tersebut diterima untuk produk yang nipis.

ABSTRACT

This thesis presents a study on laser welding of thin sheet AZ31B Magnesium (Mg) alloys using low power fiber laser. AZ31B is known as the lighter metal compared to aluminium alloys and steel with the density of 1.78 g/cm^3. Thin sheet AZ31B finds its application in automotive, aviation and also electronic devices parts such as computer casing and thin plate part in smartphone. In joining thin sheet AZ31B, laser welding is promising the best joining method compared to arc and solid state welding in producing small weldments. A low power fiber laser welding has been chosen in this research work and the welding parameters are optimized by response surface method (RSM) using Box-Behnken design (BBD) method in order to provide the most suitable laser welding condition to weld this thin AZ31B. Welding as thin as 0.6 mm of AZ31B, laser welding by double fillet lap joint configuration is selected as it can produce lower heat input with high power due to the weld geometry of fillet lap joint which beam focused at the edge of upper sheet. It was preferred since the usage of laser was overwhelming especially in manufacturing industries. The first objective of this work is to optimize the laser welding parameters to weld double fillet lap joint on AZ31B. The second objective is to investigate the relation of microstructure changes on mechanical properties of this joint. According to design of experiment (DOE) generated by BBD, 15 samples are welded and their strength were tested using tensile-shear test. From the response, a mathematical model is constructed after the analysis of variance (ANOVA) has been performed. To discuss the relationship between the shear strength and microstructure, welded samples are cut at the stable weld's cross section and are prepared for the macro and microstructure observation. Sample 9 possesses the highest shear strength with 62.0 MPa and fracture load of 740 N. A mathematical model with quadratic equation was produced to calculate the tensile shear strength. For validation of mathematical model, percentage errors for all samples are less than 8 %. It shows a high accuracy of the model and it was accepted. Welding parameters then proceed to be optimized. The optimized parameters were; pulsed energy (EP): 2.2 J; welding speed (WS): 2.0 mm/s; and angle of irradiation (AOI): 2.0˚. The percentage error for the optimized sample was 0.79 %. Vickers hardness test was performed at the weld area for sample with highest and optimized parameter sample in order to compare the result. It was observed that most of the welded samples have the solidification crack at the weld centre area of the second weld and this defect contributed to the lower tensile shear strength as observed from macrograph. For microstructure, finer grain produced at the fusion zone (FZ) of upper sheet compared to the FZ near the transition line which produced coarser and medium grain. Optimized sample was fractured at the transition region of upper sheet, meanwhile sample 1 fractured at the weld due to the crack defect. It was observed that the fracture was brittle. The fine grain produced higher hardness values compared to the coarser grain with a value of 77 Hv for the optimized sample. Optimized sample has 80.5 MPa of tensile shear strength and fracture load of 800 N which could be applied in replacing Al and steel especially for the electronic parts since the strength was acceptable for a thin product.

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LIST OF SYMBOLS

γ	Shear strength
$\approx$	Approximately
$^{\circ}$	Degree
°C	Degree Celsius
μ	Micro
$<$	Less than
$>$	More than
%	Percentage
μm	Micro meter
μs	Micro seconds
1/K	Coefficient of thermal expansion
α	Alpha
β	Beta
b_0	Constant coefficient of regression
b_i , b_{ii} , b_{ij}	Coefficient regression
eV	Ionization energy
$\sum$	Summation
ft	Feet
HV	Vickers Hardness
J/mm	Joules per millimetre
J $kg^{-1}K^{-1}$	Specific heat
J/kg	Specific heat of fusion
kW	Kilo Watt
Kg m^{-3}	Density
Kg $m^{-1}K^{-1}$	Viscosity
mm	Millimetre
m^2S^{-1}	Thermal diffusivity
MPa	Mega Pascal
N	Newton
N m^{-1}	Surface tension
N/m^3	Elastic modulus
W	Watt
W $m^{-1}K^{-1}$	Thermal conductivity
x_i, x_{ii}, x_{ij}	Factors

LIST OF ABBREVIATIONS

Al	Aluminium
Ar	Argon
AOI	Angle of Irradiation
ANOVA	Analysis of Variance
BL	Bead Length
BM	Base Metal
BW	Bead Width
BBD	Box-Behnken Design
BOP	Bead on Plate
CW	Continuous Wave
CCD	Central Composite Design
CO_2	Carbon Dioxide
DOE	Design of Experiment
EP	Pulsed Energy
EBW	Electron beam welding
EDX	Electron dispersive X-ray
FZ	Fusion Zone
FFD	Full Factorial Design
HV	Vickers Hardness
HAZ	Heat Affected Zone
HCP	Hexagonally Closely Packed
IMC	Intermetallic compound
LBW	Laser beam welding
LOF	Lack of fit
Mg	Magnesium
MIG	Metal inert gas
Nd:YAG	Neodymium: Ytterbium-Aluminium Garnet
O_2	Oxygen
OM	Optical microscope
OFAT	One factor at a time
PD	Penetration depth
PW	Pulse Wave
PMZ	Partially melted zone
QCW	Quasi-continuous wave
RSM	Response Surface Method
SEM	Scanning electron microscope
TIG	Tungsten inert gas
VIF	Value of inflation
WS	Welding Speed
Zn	Zinc

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