EFFECT OF SHOULDER TO PIN DIAMETER RATIO ON MECHANICAL AND MICROSTRUCTURAL PROPERTIES OF FRICTION STIR WELDED MAGNESIUM ALLOY AZ31B

NURUL HIDAYAH BINTI OTHMAN

Master of Science

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis/project* is adequate in terms of scope and quality for the award of the degree of Master of Science.

____

(Supervisor's Signature)

Full Name :

Position :

Date :

____

(Co-supervisor's Signature)

Full Name :

Position :

Date :

STUDENT'S DECLARATION

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.

____

(Student's Signature)

Full Name : NURUL HIDAYAH BINTI OTHMAN

ID Number : MMM14040

Date :

EFFECT OF SHOULDER TO PIN DIAMETER RATIO ON MECHANICAL AND MICROSTRUCTURAL PROPERTIES OF FRICTION STIR WELDED MAGNESIUM ALLOY AZ31B

NURUL HIDAYAH BINTI OTHMAN

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

Faculty of Mechanical Engineering

UNIVERSITI MALAYSIA PAHANG

JUNE 2018

ACKNOWLEDGEMENTS

It gives me great pleasure in expressing my gratitude to all those people who have supported me and had their contributions in making this project possible. First and foremost, I must acknowledge and thank The Almighty Allah for blessing, protecting and guiding me throughout this period. I could never have accomplished this without faith I have in the Almighty.

I would like to express my deepest gratitude to my advisor, Assoc. Prof. Dr. Mahadzir Bin Ishak @ Muhammad and my co-supervisor Mr Luqman Hakim Bin Ahmad Shah for their constant guidance, support, motivation and untiring help during this research. Thanks for providing me an opportunity to do my project work on 'Effect of Shoulder to Pin Ratio on Magnesium Alloy Friction Stir Welding'. This research project would not have been possible without the support and guided from my respected supervisor. His guidance helps me a lot in all the time of research and writing the thesis. By having a firm and knowledge supervisor gives a lot of advantages in doing very well in my thesis.

Truly thanks to the main financial support of the Ministry of Higher Education (MOHE), Malaysia for funding the tuition fee under Mybrain15 scholarship program. I would also want to thanks to all the staffs from Faculty of Mechanical Engineering and Manufacturing Process Focus Group (MPFG) for their co-operations, suggestions and time to my inquiries along the way. Not forgotten, thanks to my research group mate for their help and, support me during my time on completing this project.

It is my radiant sentiment to place on record my deepest sense of gratitude to my family especially my husband Azizul Raffar Bin Mohd Ali, my father Othman bin Hj Abas and My mother, Rosminah Binti Ahmad Dawam for their unrelenting sacrifices. For believing in me when I got up from a hard fall is the best morale boost beyond comparison. I cannot put into appropriate words for their support, love and understanding in attaining my goals. I am also grateful to family members and friends for their sacrifice, patience and understanding that more inevitable to make this research possible. There is no appropriate word that I can express for all the guidance, support, faith and concern in my study to achieve the target.

I will strive to use the gained skills and knowledge in the best possible way to archive my future. I will continue to work toward improvement, in order to attain my desired life objectives.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

DF	Degree of freedom
f	number of factor
MS	Mean square
MS_E	mean square error
N	number of the experiment
n_c	number of centre point
PRESS	predicted sum of squares
q	number of independent variables
R^2	ratio of the sum of squares of the predicted responses to the sum of squares of observed responses
RMS_E	root mean square error
S	standard error of regression
SS	total sum of squares
SS_E	sum of squares of residual
SS_R	regression sum of squares
X_i	Input variable
X_i^2	Square of variable
Y	responses
β_0	constant
β_i	first order regression coefficient
ζ	distance of axial points

LIST OF ABBREVIATIONS

ANN	Artificial neural network
ANOVA	Analysis of variance
AS	Advancing side
BM	Based metal
CCC	Central Composite Circumscribed
CCD	Central composite design
CCF	Composite face-centered
CCI	Central Composite Inscribed
DF	Degree of freedom
DOE	Design of experiment
EDM	Electrical Discharge Machining
FSW	Friction stir welding
GA	Ganeric algorithm
GMAW	Gas metal arc welding
GTAW	Gas tungsten arc welding
HAZ	Heat affected zone
LOF	Lack of fit
MEP	Mean effect plot
MIG	metal inert gas
PD	Pin diameter
PD	Pin diameter
PL	Pin length
RS	Retreating side
RSM	Response surface method
SD	Shoulder diameter
SD	Shoulder diameter
SEM	Scan Electronic microscope
SZ	Stir zone
TIG	tungsten inert gas
TMAZ	Thermomechanically affected zone
TRS	Tool rotational speed
UTS	Ultimate tensile strength
WS	Welding speed

EFFECT OF SHOULDER TO PIN DIAMETER RATIO ON MECHANICAL AND MICROSTRUCTURAL PROPERTIES OF FRICTION STIR WELDED MAGNESIUM ALLOY AZ31B

NURUL HIDAYAH BINTI OTHMAN

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

Faculty of Mechanical Engineering

UNIVERSITI MALAYSIA PAHANG

JUNE 2018

ABSTRAK

Pengurangan berat dalam industri automotif dan kapal terbang adalah satu keutamaan dalam meningkatkan ekonomi bahan api dan mengurangkan pencemaran alam sekitar. Sejak kebelakangan ini, aloi magnesium semakin penting sebagai bahan struktur ringan untuk aplikasi automotif. Kaedah kimpalan pelakuran konvensional aloi magnesium menghasilkan beberapa kecacatan seperti keliangan dan retak panas, yang menyebabkan sifat mekanik bahan merosot. Kimpalan geseran kacau (FSW) mampu menyambungkan aloi magnesium tanpa lebur, dan dengan itu, ia boleh menghapuskan masalah yang berkaitan dengan pemejalan. Kajian ini memberi tumpuan kepada kesan nisbah diameter bahu kepada pin pada mata alat kimpalan geseran kacau kepada aloi magnesium AZ31B. Dua keping aloi AZ31B dengan ketebalan 2 mm telah dikimpal dengan menggunakan mesin kisar konvensional. Nisbah bahu kepada pin diameter mata alat yang digunakan dalam eksperimen ini adalah 2.25, 2.5, 2.75, 3, 3.33, 3.66, 4.5, 5 dan 5.5. Kelajuan putaran dan kelajuan kimpalan yang digunakan dalam kajian ini adalah masing-masing 1000 rpm dan 100 mm / min. Eksperimen ini telah dijalankan mengikut reka bentuk eksperimen dengan menggunakan rekabentuk komposit pusat (CCD) dari kaedah gerak balas permukaan (RSM). Sifat-sifat mekanikal FSW telah dinilai dengan menggunakan ujian tegangan dan kekerasan. Berdasarkan kekuatan tegangan muktamad (UTS) keputusan eksperimen, model matematik telah dibangunkan bersama-sama dengan pengoptimuman parameter. Analisis logam telah dijalankan menggunakan mikroskop optik, dan mikroskop imbasan elektron (SEM). Keputusan menyatakan bahawa kekuatan tegangan tertinggi adalah di nisbah bahu kepada pin 3.33 dengan 241.39 MPa dan kecekapan kimpalan 91% daripada logam asal. Kekuatan tegangan terendah adalah di nisbah bahu kepada pin 5.5 dengan 158.11 MPa dan kecekapan kimpalan 60% daripada logam asal. Menurut analisis statistik, parameter yang paling mempengaruhi adalah diameter pin (PD) diikuti dengan diameter bahu (SD). Model matematik telah dibangunkan dengan ketepatan sehingga 0.034% ralat sisihan piawai. Ketepatan parameter dioptimumkan dengan membandingkan ramalan dan eksperimen adalah 0.46% dengan kekuatan tegangan 243.102 MPa dan kecekapan kimpalan 92% daripada logam asal pada nisbah bahu kepada pin 3.1. Butiran sama dimensi yang dapat diperhatikan di TMAZ dan zon kacau menunjukkan ubah bentuk plastik sepenuhnya. Saiz butiran zon kacau (SZ) meningkat dengan penurunan nisbah bahu kepada pin daripada nisbah 3.1-5.5 kerana input haba yang lebih tinggi. Saiz butiran di zon terkena haba (HAZ) pada kekuatan tegangan yang lebih tinggi adalah 10.234 µm manakala saiz butiran HAZ pada tahap paling rendah kekuatan tegangan adalah 54.31 µm. Adalah diperhatikan bahawa, kecacatan permukaan gahar dan kecacatan permukaan pari-pari terhasil apabila input haba yang berlebihan digunakan. Kekerasan SZ pada nisbah 3.1 adalah lebih tinggi daripada SZ pada nisbah 5.5 yang masing-masing 90.97HV dan 71.73HV. Kesimpulannya, AZ31B aloi magnesium telah berjaya dikimpal dengan menggunakan kimpalan geseran kacau. Nisbah diameter bahu kepada pin memberi kesan kepada sifat-sifat mekanikal dan mikrostruktur FSW kepada AZ31B. Nisbah optimum bahu kepada pin menunjukkan kekuatan tegangan yang lebih tinggi bagi saiz butiran samadimensi dan halus yang menunjukkan kekerasan yang lebih tinggi.

ABSTRACT

Weight reduction in automotive and aircraft industries is a main concern in improving fuel economy and reducing environmental pollutions. Recently, magnesium alloys are constantly gaining importance as lightweight structural materials for automotive applications. Conventional fusion welding methods for joining magnesium alloys produce some defects such as porosity and hot crack, which deteriorate their mechanical properties. Friction stir welding (FSW) is capable of joining magnesium alloys without melting, and thus, it can eliminate problems related to solidification. This research focuses on the effect of shoulder to pin diameter ratio on friction stir welding of magnesium alloy AZ31. Two pieces of AZ31 alloy with thickness of 2 mm were friction stir welded by using conventional milling machine. The shoulder to pin diameter ratio used in this experiment are 2.25, 2.5, 2.75, 3, 3.33, 3.66, 4.5, 5 and 5.5. The rotational speed and welding speed used in this study are 1000 rpm and 100 mm/min respectively. This experiment was conducted according to the design of experiment by using the central composite design (CCD) from a response surface method (RSM). Mechanical properties of FSW AZ31B were evaluated by using a tensile and hardness test. Based on the ultimate tensile strength (UTS) results, mathematical model was developed together with a parameter optimization. Metallurgical analyses were conducted using an optical microscope, and scanning electron microscope (SEM). Result stated that highest UTS at shoulder to pin ratio of 3.33 with 241.391 MPa and weld efficiency of 91 % from based metal. The lowest tensile strength was at shoulder to pin ratio of 5.5 with 158.11 MPa and weld efficiency of 60 % from based metal. According to statistical analysis, the most influenced parameter was the pin diameter (PD) followed by the shoulder diameter (SD). The mathematical model was developed with accuracy up to 0.034% standard deviation error. The accuracy of optimized parameter by comparing the prediction and experimental was 0.46% with tensile strength 243.10 MPa and weld efficiency of 92 % from based metal at shoulder to pin ratio 3.1. Equiaxed grains were observed at the thermomechanically effected zone (TMAZ) and stir zone (SZ) indicating fully plastic deformation. The grain size of stir zone increased with decreasing shoulder to pin ratio from ratio 3.1 to 5.5 due to higher heat input. The heat affected zone (HAZ) grain size at higher tensile strength is 10.234 µm while HAZ grain size at lowest tensile strength is 54.31 µm. It is observed that, surface galling and faying surface defect is produced when excessive heat input is applied. It was found that SZ hardness at ratio 3.1 is higher than SZ at ratio 5.5 that are 90.97HV and 71.73HV respectively. In conclusion, the magnesium alloy AZ31B was successfully welded by using friction stir welding. Shoulder to pin diameter ratio give effect to the mechanical and microstructural properties of AZ31B FSW. The optimum shoulder to pin ratio shows higher tensile strength with fine and equiaxed grain size that indicate higher hardness.

REFERENCES

Abbaschian, R., Abbaschian, L., & Reed-Hill, R. E. (2009). *Physical Metallurgy Principles*. Cengage.

Abbasi Gharacheh, M., Kokabi, A. H., Daneshi, G. H., Shalchi, B., & Sarrafi, R. (2006). The influence of the ratio of “rotational speed/traverse speed” (ω/v) on mechanical properties of AZ31 friction stir welds. *International Journal of Machine Tools and Manufacture*, *46*(15), 1983–1987.

Afrin, N., Chen, D. L., Cao, X., & Jahazi, M. (2008). Microstructure and tensile properties of friction stir welded AZ31B magnesium alloy. *Materials Science and Engineering A*, *472*(1–2), 179–186.

Albakri, A. N., Mansoor, B., Nassar, H., & Khraisheh, M. K. (2013). Thermo-mechanical and metallurgical aspects in friction stir processing of AZ31 Mg alloy—A numerical and experimental investigation. *Journal of Materials Processing Technology*, *213*(2), 279–290.

Arbegast, W. J. (2003). Friction Stir Joining : Characteristic Defects. *Advanced Materials Processing Center MET*, *6*(October), 1–30.

Assidi, M., Fourment, L., Guerdoux, S., & Nelson, T. (2010). Friction model for friction stir welding process simulation : Calibrations from welding experiments. *International Journal of Machine Tools and Manufacture*, *50*(2), 143–155.

Avedesian, M. M., & Baker, H. (1999). *Magnesium & Magnesium Alloys: : ASM Specialty Handbooks*. ASM International.

Azom. (2012). Magnesium AZ31B Alloy (UNS M11311). Retrieved from http://www.azom.com/article.aspx?ArticleID=6707

Babu, A. S., & Devanathan, C. (2013). An Overview of Friction Stir Welding. *International Journal of Research in Mechanical Engineering & Technology*, *3*(2), 259–265.

Barlas, Z., & Ozsarac, U. (2012). Effects of FSW Parameters on Joint Properties of AlMg3 Alloy. *Welding Journal*, *91*(1), 16S–22S.

Benyounis, K. Y., & Olabi, A. G. (2008). Optimization of different welding processes using statistical and numerical approaches - A reference guide. *Advances in Engineering Software*, *39*(6), 483–496.

Blawert, C., Hort, N., & Kainer, K. U. (2004). Automotive Applications of Magnesium and Its Alloys. *Trans. Indian Inst. Met.*, *57*(4), 397–408.

Bradley, N. (2007). *The Response Surface Methodology*. Indiana University of South Bend.

Burford, D., Widener, C., & Tweedy, B. (2006). Advances in Friction Stir Welding for aerospace applications. *6th AIAA Aviation Technology, Integration and Operations Conference (ATIO)*, *6*(14), 3–7.

Cao, X., & Jahazi, M. (2009). Effect of welding speed on the quality of friction stir welded butt joints of a magnesium alloy. *Materials and Design*, *30*(6), 2033–2042.

Cao, X., & Jahazi, M. (2011). Effect of tool rotational speed and probe length on lap joint quality of a friction stir welded magnesium alloy. *Materials & Design*, *32*(1), 1–11.

Carley, K. M., Kamneva, N. Y., & Reminga, J. (2004). *Response Surface Methodology*. *CMU SCS ISRI*.

Choi, D.-H., Kim, S.-K., & Jung, S.-B. (2013). The microstructures and mechanical properties of friction stir welded AZ31 with CaO Mg alloys. *Journal of Alloys and Compounds*, *554*, 162–168.

Cochran, W. G., & Cox, G. M. (1992). *Experimental Designs*. New Delhi: Asia Publishing House.

Coelho, R. S., Kostka, A., Santos, J. F. dos, & Kaysser-Pyzalla, A. (2012). Friction-stir dissimilar welding of aluminium alloy to high strength steels: Mechanical properties and their relation to microstructure. *Materials Science and Engineering: A*, *556*, 175–183.

Darras, B. M., Khraisheh, M. K., Abu-Farha, F. K., & Omar, M. A. (2007). Friction stir processing of commercial AZ31 magnesium alloy. *Journal of Materials Processing Technology*, *191*(1–3), 77–81.

Dawood, H. I., Mohammed, K. S., & Rajab, M. Y. (2014). Advantages of the Green Solid State FSW over the Conventional GMAW Process. *Advances in Materials Science and Engineering*, *2014*, 1–10.

Dhanapal, A., Rajendra Boopathy, S., Balasubramanian, V., Chidambaram, K., & Zaman, A. R. T. (2013). Experimental Investigation of the Corrosion Behavior of Friction Stir Welded AZ61A Magnesium Alloy Welds under Salt Spray Corrosion Test and Galvanic Corrosion Test Using Response Surface Methodology. *International Journal of Metals*, *2013*, 1–18.

Dhancholia, D. D., Sharma, A., & Vyas, C. (2014). Optimisation of Friction Stir Welding Parameters for AA 6061 and AA 7039 Aluminium Alloys by Response Surface Methodology (RSM). *International Journal of Advanced Mechanical Engineering.*, *4*(5), 565–571.

Dorbane, A., Ayoub, G., Mansoor, B., Hamade, R. F., Kridli, G., Shabadi, R., & Imad, A. (2016). Microstructural observations and tensile fracture behavior of FSW twin roll cast AZ31 Mg sheets. *Materials Science and Engineering A*, *649*, 190–200.

Elangovan, K., & Balasubramanian, V. (2008). Influences of tool pin profile and tool shoulder diameter on the formation of friction stir processing zone in AA6061 aluminium alloy. *Materials & Design*, *29*(2), 362–373.

Elatharasan, G., & Kumar, V. S. S. (2013). An experimental analysis and optimization of process parameter on friction stir welding of AA 6061-T6 aluminum alloy using RSM. *Procedia Engineering*, *64*, 1227–1234.

Esparza, J. A., Davis, W. C., Trillo, E. A., & Murr, L. E. (2002). Friction-stir welding of magnesium alloy AZ31B. *J. Mater. Sci. Letters 21*, 917–920.

Firouzdor, V., & Kou, S. (2009). Al-to-Mg Friction Stir Welding : Effect of Positions of Al and Mg with Respect to the Welding Tool. *Welding Journal*, *88*(November), 213–224.

Fleming, S. (2012). *An Overview of Magnesium based Alloys for Aerospace and Automotive Applications*.

Gene Mathers. (2002). *The welding of aluminum and its alloys* (1st ed.). England.

Gibson, B. T., Lammlein, D. H., Prater, T. J., Longhurst, W. R., Cox, C. D., Ballun, M. C., & Dharmaraj, K. J. (2013). Friction stir welding: Process, automation, and control. *Journal of Manufacturing Processes*, *16*(1), 1–18.

Goloborodko, A., Ito, T., Yun, X., Motohashi, Y., & Itoh, G. (2004). Friction Stir Welding of a Commercial 7075-T6 Aluminum Alloy: Grain Refinement, Thermal Stability and Tensile Properties. *Materials Transactions*, *45*(8), 2503–2508.

Hartmann, M., Böhm, S., Schüddekopf, S., Hartmann, M., Böhm, S., & Schüddekopf, S. (2014). Influence of Surface Roughness of Tools on the Friction Stir Welding Process Influence of Surface Roughness of Tools on the Friction Stir Welding Process. *Journal of Welding and Joining*, *32*(6), 22–28.

Hirano, S., Okamoto, K., Doi, M., Okamura, H., Hisanori, Inagaki, M., & Aono, Y. (2003). Microstructure of dissimilar joint interface of magnesium alloy and aluminum alloy by friction stir welding. *Quarterly J. Japan Welding Society 21*, 539–545.

Hu, H., Yu, A., & Li, N. (2003). Potential magnesium alloys for high temperature die cast automotive applications: A review. *Materials and Manufacturing Processes 2003*, *5*(18), 687–717.

Huang, Y. X., Han, B., Tian, Y., Liu, H. J., Lv, S. X., Feng, J. C., Li, Y. (2011). New technique of filling friction stir welding. *Science and Technology of Welding & Joining*, *16*(6), 497–501.

Industy, E. (2013). A weld of difference. *Insight Publishers*, 1–2.

Jagadeesha, C. B. (2014). Dissimilar friction stir welding between aluminum alloy and magnesium alloy at a low rotational speed. *Materials Science and Engineering: A*, *616*, 55–62.

Jannet, S., Mathews, P. K., & Raja, R. (2015). Optimization of process parameters of friction stir welded AA 5083-O aluminum alloy using Response Surface Methodology. *Bulletin of the Polish Academy of Sciences: Technical Sciences*, *63*(4), 851–855.

Jata, K. V., Sankaran, K. K., & Ruschau, J. J. (2000). Friction-stir welding effects on microstructure and fatigue of aluminum alloy 7050-T7451. *Metallur. Mater. Trans.*, *31*, 2181–2192.

Khan, N. Z., Khan, Z. A., & Siddique, A. N. (2015). Effect of Shoulder Diameter to Pin Diameter (D/d) Ratio on Tensile Strength of Friction Stir Welded 6063 Aluminium Alloy. *Materials Today: Proceedings*, *2*(4–5), 1450–1457.

Kwon, Y. J. J., Shigematsu, I., & Saito, N. (2008). Dissimilar friction stir welding between magnesium and aluminum alloys. *Materials Letters*, *62*(23), 3827–3829.

Lakshminarayanan, a. K., & Balasubramanian, V. (2012). Assessment of sensitization resistance of AISI 409M grade ferritic stainless steel joints using Modified Strauss test. *Materials and Design*, *39*, 175–185.

Lee, K., & Kumai, S. (2006). Characterization of Intermetallic Compound Layer Formed at the Weld Interface of the Defocused Laser Welded Low Carbon Steel / 6111 Aluminum Alloy Lap Joint. *Materials Transactions*, *47*(4), 1178–1185.

Lee, W. B., Yeon, Y. M., & Jung, S. B. (2003). Joint properties of friction stir welded AZ31B-H24 magnesium alloy. *Mater. Sci. Technol. 19*, 785–790.

Liu, D., Xin, R., Zhao, L., & Hu, Y. (2017). Effect of textural variation and twinning activity on fracture behavior of friction stir welded AZ31 Mg alloy in bending tests. *Journal of Alloys and Compounds*, *693*, 808–815.

Liu, H. J., Fujii, H., Maeda, M., & Nogi, K. (2003). Tensile properties and fracture locations of friction-stir-welded joints of 2017-T351 aluminum alloy. *Journal of Materials Processing Technology*, *142*(3), 692–696.

Liu, H., & Zhang, H. (2009). Repair welding process of friction stir welding groove defect. *Transactions of Nonferrous Metals Society of China*, *19*(3), 563–567.

Liu, L. M., Tan, J. H., Zhao, L. M., & Liu, X. J. (2008). The relationship between microstructure and properties of Mg/Al brazed joints using Zn filler metal. *Materials Characterization*, *59*(4), 479–483.

Lohwasser, D., & Chen, Z. (2010). *Friction stir welding: From basics to applications*. Cambridge, England: Woodhead Publishing Limited.

MadhuSudhan, R., & Ramanaiah, N. (2015). Influence Of Weld Parameters On Mechanical Properties Of Dissimilar Friction Stir Welded Al Alloy Flat Plates. *IJREAT International Journal of Research in Engineering & Advance Technology*, *2*(6), 202–208.

Malarvizhi, S., & Balasubramanian, V. (2012). Influences of tool shoulder diameter to plate thickness ratio (D/T) on stir zone formation and tensile properties of friction stir welded dissimilar joints of AA6061 aluminum–AZ31B magnesium alloys. *Materials & Design*, *40*, 453–460.

Mao, Y., Ke, L., Liu, F., Liu, Q., Huang, C., & Xing, L. (2014). Effect of tool pin eccentricity on microstructure and mechanical properties in friction stir welded 7075 aluminum alloy thick plate. *Materials and Design*, *62*, 334–343.

Masoudian, A., Tahaei, A., Shakiba, A., Sharifianjazi, F., & Mohandesi, J. A. (2014). Microstructure and mechanical properties of friction stir weld of dissimilar AZ31-O magnesium alloy to 6061-T6 aluminum alloy. *Transactions of Nonferrous Metals Society of China*, *24*(5), 1317–1322.

Mironov, S., Onuma, T., Sato, Y. S., & Kokawa, H. (2015). Microstructure evolution during friction-stir welding of AZ31 magnesium alloy. *Acta Materialia*, *100*, 301–312.

Mironov, S., Onuma, T., Sato, Y. S., Yoneyama, S., & Kokawa, H. (2017). Tensile behavior of friction-stir welded AZ31 magnesium alloy. *Materials Science and Engineering A*, *679*(October 2016), 272–281.

Mishra, R. S., & Ma, Z. Y. (2005). Friction stir welding and processing. *Materials Science and Engineering: R: Reports*, *50*(1–2), 1–78.

Motalleb-nejad, P., Saeid, T., Heidarzadeh, A., Darzi, K., & Ashjari, M. (2014). Effect of tool pin profile on microstructure and mechanical properties of friction stir welded AZ31B magnesium alloy. *Materials & Design*, *59*(October 2015), 221–226.

Nagasawa, T., Otsuka, M., Yokota, T., & Ueki, T. (2016). Structure and Mechanical Properties of Friction Stir Weld Joints of Magnesium Alloy AZ31. In S. N. Mathaudhu, A. A. Luo, N. R. Neelameggham, E. A. Nyberg, & W. H. Sillekens (Eds.), *Essential Readings in Magnesium Technology* (pp. 517–521). Cham: Springer International Publishing.

Naik, B. S., Chen, D. L., Cao, X., & Wanjara, P. (2014). Texture development in a friction stir lap-welded AZ31B magnesium alloy. *Metallurgical and Materials Transactions A*, *45*(10), 4333–4349.

Oosterkamp, A., Oosterkamp, L. D., & Nordeide, A. (2004). " Kissing Bond " Phenomena in Solid-State Welds of Aluminum Alloys. *Welding Journal*, (August), 225–231.

Othman, N. H., Ishak, M., & Shah, L. H. (2017). Effect of shoulder to pin ratio on magnesium alloy Friction. *IOP Conference Series: Materials Science and Engineering*, *238*, 12008.

Othman, N. H., Udin, N., Ishak, M., & Shah, L. H. (2016). Effect of Taper Pin Ratio on Microstructure and Mechanical Property of Friction Stir Welded AZ31 Magnesium Alloy. *International Journal Of Chemical, Molecular,Nuclear, Materials and Metallurgical Engineering*, *10*(5), 619–622.

Padmanaban, G., & Balasubramanian, V. (2009). Selection of FSW tool pin profile, shoulder diameter and material for joining AZ31B magnesium alloy - An experimental approach. *Materials and Design*, *30*(7), 2647–2656.

Park, J. W., Park, S. J., & Shin, K. S. (2017). Effects of Tensile Twinning on the Stretch Formability of Mg. *Met. Mater. Int*, *23*(3), 444–449.

Patel, N., Bhatt, K. D., & Mehta, V. (2016). Influence of Tool Pin Profile and Welding Parameter on Tensile Strength of Magnesium Alloy AZ91 During FSW. *Procedia Technology*, *23*, 558–565.

Polmear, I. J. (2005). 5 – Magnesium alloys. In *Light Alloys* (pp. 237–297).

Pourahmad, P., & Abbasi, M. (2013). Materials flow and phase transformation in friction stir welding of Al 6013/Mg. *Transactions of Nonferrous Metals Society of China*, *23*(5), 1253–1261.

Rajakumar, S., Muralidharan, C., & Balasubramanian, V. (2010). Establishing empirical relationships to predict grain size and tensile strength of friction stir welded AA 6061-T6 aluminium alloy joints. *Transactions of Nonferrous Metals Society of China*, *20*(10), 1863–1872.

Rajakumar, S., Muralidharan, C., & Balasubramanian, V. (2011). Influence of friction stir welding process and tool parameters on strength properties of AA7075-T6 aluminium alloy joints. *Materials & Design*, *32*(2), 535–549.

Rajakumar, S., Razalrose, a., & Balasubramanian, V. (2013). Friction stir welding of AZ61A magnesium alloy: A parametric study. *International Journal of Advanced Manufacturing Technology*, *68*(1–4), 277–292.

Ramulu, P. J., Narayanan, R. G., Kailas, S. V., & Reddy, J. (2012). Internal defect and process parameter analysis during friction stir welding of Al 6061 sheets. *The International Journal of Advanced Manufacturing Technology*, *65*(9–12), 1515–1528.

Reddy, G. M., Mastanaiah, P., Murthy, C. V. S., & Mohandas, T. (2006). Microstructure , Residual Stress Distribution and Mechanical Properties of Friction-Stir AA 6061 Aluminium Alloy Weldments. *Indian Society for Non-Destructive Testing Hyderabad Chapter*.

Regev, M., & Spigarelli, S. (2013). Plastic Deformation Mechanisms of Base Material and Friction Stir Welded AZ31B-H24 Magnesium Alloy. *Materials Sciences and Applications*, *4*(June), 357–364.

Ren, S. R., Ma, Z. Y., & Chen, L. Q. (2007). Effect of welding parameters on tensile properties and fracture behavior of friction stir welded Al – Mg – Si alloy. *Scripta Materialia*, *56*, 69–72.

Sahu, G. (2015). A Brief Review on MG Alloys Their Properties and Application. *International Journal of Advance Research In Science and Engineering (IJERSE)*, *8354*(4), 65–71.

Saravanan, V., Rajakumar, S., Banerjee, N., & Amuthakkannan, R. (2016). Effect of shoulder diameter to pin diameter ratio on microstructure and mechanical properties of dissimilar friction stir welded AA2024-T6 and AA7075-T6 aluminum alloy joints. *The International Journal of Advanced Manufacturing Technology*.

Schultz, R. A., & Haupricht, W. J. (1999). Trends in aluminium use for passenger cars and light trucks in North America. *Light Metal Age*, *57*(1–2), 108–113.

Seighalani, K. R., Givi, M. K. B., Nasiri, a. M., & Bahemmat, P. (2010). Investigations on the effects of the tool material, geometry, and tilt angle on friction stir welding of pure titanium. *Journal of Materials Engineering and Performance*, *19*(7), 955–962.

Sevvel, P., & Jaiganesh, V. (2014). Characterization of mechanical properties and microstructural analysis of friction stir welded AZ31B Mg alloy thorough optimized process parameters. *Procedia Engineering*, *97*(May), 741–751.

Shanmuga Sundaram, N., & Murugan, N. (2010). Tensile behavior of dissimilar friction stir welded joints of aluminium alloys. *Materials & Design*, *31*(9), 4184–4193.

Shigematsu, I., Kwon, Y.-J., & Saito, N. (2009). Dissimilar Friction Stir Welding for Tailor-Welded Blanks of Aluminum and Magnesium Alloys. *Materials Transactions*, *50*(1), 197–203.

Standard Test Method for Knoop and Vickers Hardness of Materials. (2010). In *ASTM international*. http://doi.org/10.1520/E0384-10E02

Standard Test Methods for Tension Testing of Metallic Materials. (2010). In *ASTM standard E8/E8M* (pp. 1–27).

Suhuddin, U. F. H. R., Mironov, S., Sato, Y. S., Kokawa, H., Lee, C.-W., & A. (2009). Grain structure evolution during friction-stir welding of AZ31 magnesium alloy. *Acta Materialia*, *57*, 5406–5418.

Sundaram, M., & Visvalingam, B. (2016). Optimizing the Friction Stir Spot Welding Parameters to Attain Maximum Strength in Al / Mg Dissimilar Joints Optimizing the Friction Stir Spot Welding Parameters to Attain Maximum Strength in Al / Mg Dissimilar Joints, *34*(3).

Sutton, M. A., Yang, B., Reynolds, A. P., & Taylor, R. (2002). Microstructural studies of friction stir welds in 2024-T3 aluminum. *Mater. Sci. Eng. A*, *323*, 160–166.

Ugender, S., Kumar, A., & Reddy, A. S. (2014a). Microstructure and Mechanical Properties of AZ31B Magnesium Alloy by Friction Stir Welding. *Procedia Materials Science*, *6*(Icmpc), 1600–1609.

Ugender, S., Kumar, D. A., & Reddy, A. S. (2014b). Influence of Rotational Speed on Microstructure and Mechanical Properties of Friction Stir Welded AZ31B Magnesium Alloy. *Advance Research and Innovations in Mechanical, Material Science, Industrial Engineering and Management - ICARMMIEM-2014*, 229–232.

Vijayavel, P., Balasubramanian, V., & Sundaram, S. (2014). Effect of shoulder diameter to pin diameter (D/d) ratio on tensile strength and ductility of friction stir processed LM25AA-5% SiCp metal matrix composites. *Materials and Design*, *57*, 1–9.

Weisman, C., & Kearns, W. H. (2010). Welding processes - Arc and gas welding and cutting, brazing, and soldering. *Welding Handbook*, *2*(7).

Xie, G. M., Ma, Z. Y., Luo, Z. a., Xue, P., & Wang, G. D. (2011). Effect of Rotation Rate on Microstructures and Mechanical Properties of FSW Mg-Zn-Y-Zr Alloy Joints. *Journal of Materials Science and Technology*, *27*(12), 1157–1164. http://doi.org/10.1016/S1005-0302(12)60012-7

Xin, R., Liu, D., Shu, X., Li, B., Yang, X., & Liu, Q. (2016). Influence of welding parameter on texture distribution and plastic deformation behavior of as-rolled AZ31 Mg alloys. *Journal of Alloys and Compounds*, *670*, 64–71.

Xu, N., & Bao, Y. (2016). Enhanced mechanical properties of tungsten inert gas welded AZ31 magnesium alloy joint using two-pass friction stir processing with rapid cooling. *Materials Science and Engineering A*, *655*, 292–299.

Xu, X., Yang, X., Zhou, G., & Tong, J. (2012). Microstructures and fatigue properties of friction stir lap welds in aluminum alloy AA6061-T6. *Materials & Design*, *35*, 175–183.

Xunhong, W., & Kuaishe, W. (2006). Microstructure and properties of friction stir butt-welded AZ31 magnesium alloy. *Materials Science and Engineering A*, *431*(1–2), 114–117.

Yan, Y., Zhang, D., Qiu, C., Zhang, W., Yong, Y. A. N., Da-tong, Z., … Wen, Z. (2010). Dissimilar friction stir welding between 5052 aluminum alloy and AZ31 magnesium alloy. *Transactions of Nonferrous Metals Society of China*, *20,* s619–s623.

Yang, R.-T., & Chen, Z.-W. (2013). A study on fiber laser lap welding of thin stainless steel. *International Journal of Precision Engineering and Manufacturing*, *14*(2), 207–214.

Yildirim, H. C., & Marquis, G. B. (2012). Fatigue strength improvement factors for high strength steel welded joints treated by high frequency mechanical impact. *International Journal of Fatigue*, *44*, 168–176.

Young, J. P., Askari, H., Hovanski, Y., Heiden, M. J., & Field, D. P. (2015). Thermal microstructural stability of AZ31 magnesium after severe plastic deformation. *Materials Characterization*, *101*, 9–19.

Zeng, R. C., Dietzel, W., Zettler, R., Gan, W. M., & Sun, X. X. (2014). Microstructural evolution and delayed hydride cracking of FSW-AZ31 magnesium alloy during SSRT. *Transactions of Nonferrous Metals Society of China (English Edition)*, *24*(10), 3060–3069.