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System Integration of a Friction Stir Welding Machine with a Customized Traverse Controlled Table

Nur'Amirah Busu, Mohammad Shamil Jaffarullah, Mohd Saiful Bahari Shaari, Cheng Yee Low*, Armansyah, Ahmed Jaffar

Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

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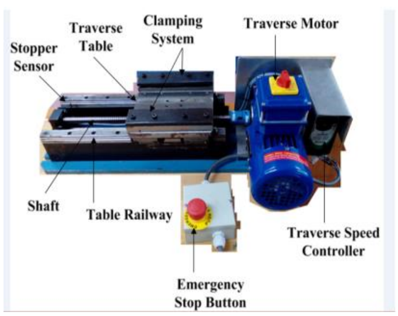
*Corresponding author
chengyee.low@salam.uitm.edu.my

Graphical abstract



Abstract

Friction stir welding (FSW) is a promising joining process that offers a high potential to be widely applied across industry sectors such as automotive, shipbuilding and aerospace. Nevertheless the path force can vary significantly due to the fluctuation of workpiece temperature and other process variations, thus results in inconsistency in weld microstructure. This paper describes the system integration of a FSW machine with a focus on the development of a traverse controlled table in order to produce a consistent temperature and path force along the weld path in FSW process. Aluminium alloy 6061 plate and a FSW's tool with a flat shoulder and conical pin without thread are used. Advantages of such an approach include wormhole generation will be eliminated, a high quality of weld microstructure can be produced and the synchronization between the temperature and path force can be obtained.

Keywords: Friction stir welding, control system, force control, path force, temperature, aluminium alloy 6061, traverse controlled table

1.0 INTRODUCTION

Friction stir welding (FSW) was invented by Wayne Thomas in 1991 at The Welding Institute (TWI), Cambridge in United Kingdom and patented in 1995 [1]. This FSW process is a solid state joining process that is gaining popularity in the manufacturing sector and mostly used for welding soft metals or alloys such as aluminium and copper. The FSW also has been found to be effective for joining plates with different type of joint configurations such as square butt, combined butt and lap, edge butt and others.

The advantages of FSW include environmentally friendly since there is no filler material and no fumes, increased mechanical strength, reduced porosity, no spatter, low shrinkage and low distortion. Since during the joining process, the parent materials remain in their solid state compared to fusion welding which require the parent materials to be melted first. The FSW process widely used in industries like automotive, shipbuilding, civil aviation and aerospace [1].

The FSW process begins by clamping the work pieces to be welded tightly to a backing plate. The process of FSW consists of four different stages that are plunge phase, dwell phase, welding phase and retract phase. In plunge stage, the rotating tool is plunge – in vertically into the joint line between the work pieces. Then, followed by dwell stage, the tool is held steady relative to the work piece while the tool still rotating. Then, heat distributes into the surrounding material leads to the rising of temperature and material softens. The welding process then takes place by moving the tool along the joint line of the work pieces. When the weld distance is covered and reaching the end – point the tool is retracted from the workpiece while it is still rotating. This leaves a keyhole on the workpiece [1, 2].

In FSW process, the main process parameters that involved are tool rotation speed, traverse speed, plunge depth, and tool's dimension [3]. The heat generation rate commonly controlled by the tool rotation speed, so that increasing the traverse speed decreases the average heat input. This will lead to a slightly lower material temperature and increased tool forces [4]. Constant process parameter runs can result in poor quality welds due to improper fixturing of the workpiece, structural deflections, machine geometric errors, change in thermal boundary conditions, and material inconsistencies along the weld path [5]. Thus, utilizing traverse speed as the control variable can produce a weld with more consistent microstructure qualities while maintaining a constant plunge depth.

The most relevant forces subjected to the tool during FSW are path force, axial force, and side force. This paper will focus on path force which is a result of the material's resistance to the tool movement along the joint line. This force will be influenced by the welding parameters which is the faster welding usually generates more force and the type of the welded material such as the temperature dependent material hardness. By maintaining the constant traverse force, even in the presence of gaps and wormhole generation during the welding process is eliminated by regulating the traverse force [6].

The aims of this paper are to introduce the combination of temperature and path force control analysis in FSW using the traverse controlled table that specifically designed to control the traverse motion of the welding table during the FSW process. This paper mainly focused on the traverse stage of the FSW process and not considered for plunge and retract stage.

2.0 REVIEW OF PATH FORCE CONTROL IN FSW

Currently, there was a lot of research that investigated and analyzed the force controller in the FSW process in order to obtain good quality of weld microstructure by regulating the axial force and path force along the weld path. This force can be controlled by adjusting the vertical position, the traverse speed, or the rotation rate of the tool [7].

Xin Zhao *et al*. [8] have been designed the feedback controller for the path force by using the Polynomial Pole Placement (PPP) technique in order to regulate the path force at a constant value. They focused on the designing of controller based on empirical dynamic models that was implemented in a Smith Predictor – Corrector (SPC) structure to compensate for inherent equipment communication delays for 6061 - T6 aluminium alloy, butt welded. The tool used was threaded, contains three flats and has a scrolled shoulder. The tilt angle was set to zero. While force signal was filtered with hardware via a low pass filter.

The result was validated with conducting of three sets of experiments which were implemented to track constant reference path forces and the plunge depth and tool traverse rate are constant, to examine the controller's performance when welding along skin - to - skin gaps and to demonstrate the ability of the path controller to eliminate the generation wormholes during the welding process. The results validated that the path force controller was able to track constant path, even when gaps were encountered along the weld path and the wormhole defect during the welding process can be eliminated.

3.0 TEMPERATURE AND PATH FORCE CONTROL SYSTEM

Figure 1 illustrates the flow of the combined temperature and path force analysis that will conduct using experimentation in order to obtain the real – time data for both temperature and path force result. The experimental procedure begins with the initial preparation of experimental equipment.

The conventional milling machine (refer to: Figure 2) will be calibrated before run the experiment. The traverse controlled table that was specially designed will be attached to the conventional milling machine and other equipment of National Instrument will be setup as shown in Figure 2.

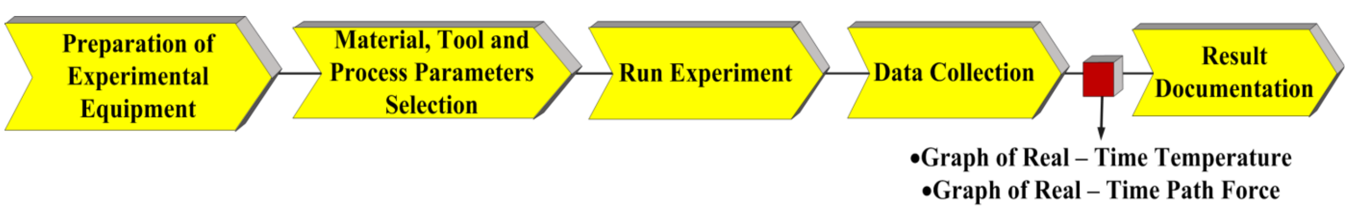


Figure 1 Experiment flowchart for temperature and path force analysis in FSW

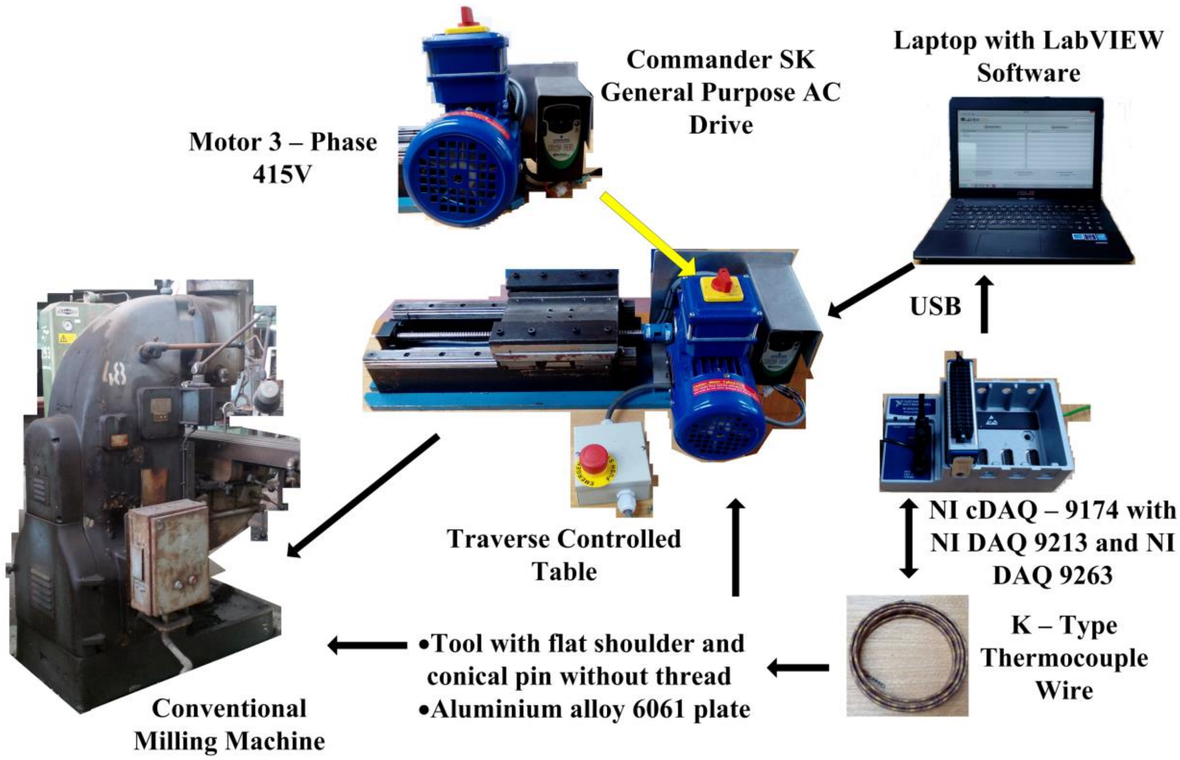


Figure 2 System integration of a FSW machine with a traverse controlled table

This experiment will be conducted using aluminium alloy 6061 - T6 with dimensions of 230mm x 130mm and 6mm thickness was selected for this experiment. This experiment will be performed using bead – on – plate method, which is commonly used in initial testing to analyze the process without disturbances generated by gaps between the parts. This method does not involve the actual joining of parts; rather, the pin processes solid material. The input process parameters are selected as the traverse speed and tool rotational speed, while plunge depth of 0.5mm from the bottom surface of the workpiece and tilt angle of 3° are held as constant during all runs. During each run, the traverse speed will vary between 1mm/s to 5mm/s while the tool rotational speed will be set to 650rpm, 950rpm and 1400rpm respectively.

The experiment then will be run according to the selected process parameter using the FSW tool with the flat shoulder with a diameter of 20mm and conical pin without thread, with diameter of 6mm for pin and 5mm of the pin's base while the height of the pin is 5mm. The tool was held tightly to the spindle at the conventional milling machine during rotating and plunged into the workpiece. The traverse motion will be help by the traverse controlled table. From this experiment, graphs of real – time temperature and path force will be obtained and the details result will be collected for documentation.

By referring to Figure 3, this table was accommodated with the general purpose AC driver, which is Commander SK from Emerson Industrial Automation that was ideal for a wide range of industrial automation and process control applications This traverse speed controller will send the input to the traverse motor to control the shaft rotation according to the input frequency so that the traverse table will move according to the desired speed on the traverse railway during the FSW process. Besides that, this table was developed with a backing plate and a clamping system which is the main important aspect that need to be highlighted during the FSW process. This clamping system is used to clamp the workpiece tightly so that any unnecessary movement will be avoid. Hence the FSW process will be running smoothly and the accuracy of the result obtained can be ensured. For safety precaution, a stopper sensor was attached at the end of the traverse railway, so that when the traverse table reached the end of the railway and touch the stopper sensor, the traverse motor will automatically stop. An emergency stop button also can be used for any emergency condition during the FSW process.

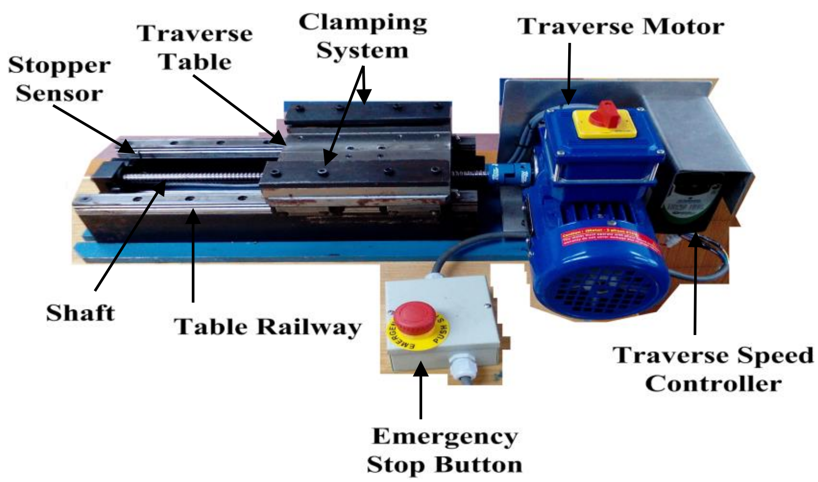


Figure 3 Traverse controlled table configuration

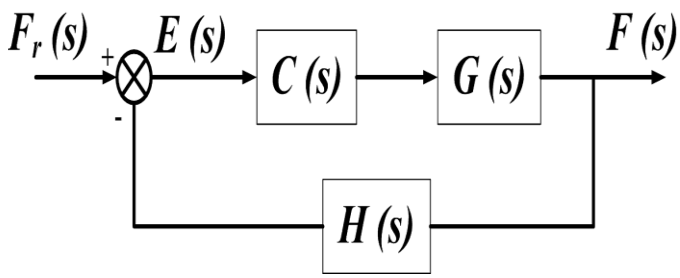


Figure 4 Closed – loop control system for path force control in FSW

Temperature is measured using type K thermocouple wire (refer to: Figure 2) from fibreglass attached to the FSW tool and the workpiece in order to analyze the fluctuation of the temperature and collect the result in real – time during the FSW process. During the experiment, the temperature measurement in real – time will be transmitted to the NI DAQ 9213 which is a thermocouple input module that attached with NI compactDAQ – 9174. The graph of the real – time temperature can be obtained with the Measurement and Automation Explorer (NI MAX). Thus, NI DAQ 9263 will read the value for the traverse force during the FSW process.

Path force in this experiment will be directly controlled with LabVIEW software with a programming of path force control attached to traverse speed controller. The closed – loop system block diagram for path force is as shown in Figure 4, where Fr indicates the reference force, F is the measured force, E is the error between the reference and measured forces, C is the controller transfer function, G is the model force process transfer function and H is the feedback control signal that will give a command to adjust the traverse speed until the measured forces satisfied the reference force. The graph of real – time path force will be obtained.

Lastly, both temperature and path force control system need to support each other since both of it can help in maintaining the weld quality even in the presence of gaps. Besides that, the path force controller was needed to eliminate the generation of void defects and wormhole generation during the FSW process. It is an advantage to combine the both control methods, so that during the FSW process both a certain temperature and a specified path force is maintained.

4.0 SUMMARY

This paper describes the development of a traverse controlled table for friction stir welding using a milling machine with the aim of improving the performance of the FSW process by the combination of temperature and path force control system. The developed prototype enables experiment and a wide range of analysis to be carried out to determine suitable parameters for a robust force control.

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References

[1] Armansyah, Almanar, I. P., M. Saiful Bahari Shaari, M. Shamil Jaffarullah, Nur'Amirah Busu, and M. Amlie A. Kasim. 2014. Temperature Distribution in Friction Stir Welding Using Finite Element Method. *International Journal of Mechanical, Aerospace, Industrial and Mechatronics Engineering.* 8(10): 1625-1630.

[2] Schmidt, H., Hattel, J., and Wert, J. 2004. An Analytical Model for the Heat Generation in Friction Stir Welding. *Modelling and Simulation in Materials Science and Engineering.* 12: 143-157.

[3] Alfaro, I., Fratini, L., Cueto, E., and Chinesta, F. 2008. Numerical Simulation of Friction Stir Welding by Natural Element Methods. *International Journal of Material Forming.*

[4] Tyler Davis, A., Yung Shin, C., Fellow, ASME, and Bin Yao, Member, IEEE. 2011. Observed-Based Adaptive Robust Control of Friction Stir Welding Axial Force. *IEEE/ASME Transactions on Mechatronics.* 16(6): 1032-1039.

[5] Thomas Oakes and Robert G. Landers. 2009. Design and Implementation of a General Tracking Controller for Friction Stir Welding Processes. *2009 American Control Conference, Hyatt Regency Riverfront*. St. Louis, MO, USA. 10–12 June 2009. 5576–5581.

[6] Xin Zhao, Prabhanjana Kalya, Robert G. Landers, and Krishnamurthy, K. 2009. Path Force Control for Friction Stir Welding Processes. *AFRL - RX - WP - TP - 2009 – 4127. Air Force Research Laboratory, Materials and Manufacturing Directorate*.

[7] Longhurst, W. R., Strauss, A. M., Cook, G. E., Cox, C. D., Hendricks, C. E., Gibson, B. T. and Dawant, Y. S. 2010. Investigation of Force Controlled Friction Stir Welding for Manufacturing and Automation. *Proc. IMechE Vol. 224 Part B: Journal of Engineering Manufacture*. 224: 937-949.

[8] Zhao, X., Kalya, P., Landers, R. G., and Krishnamurthym, K. 2009. Empirical Dynamic Modeling of Friction Stir Welding Processes. *Journal of Manufacturing Science and Engineering.* 131(2).