
Performance of Non-rotating Shoulder Tool in Weld Joint and Forces of Friction Stir Welding

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Abstract

Lighter construction in the structure of transportation make industries rely on aluminum as construction materials and new technology of joining such as friction stir welding become increasingly applied. Since welding force in the process is considered high so that many researches are focused on this area. In this research, a new method of welding by using non-rotating shoulder tool and combined with pre heating was investigated. The result give confirmation that the methods was proven to be adequate to produce sound welding when the parameters chosen was rightly. Even though the method was able to lower the force but significant results only observed for Fx while another force, i.e. Fz, did not have similar significant results. Non-rotating shoulder with additional heat input has limited capability in lowering forces in Fz because of its design, while has very good capability to lower Fx. Also, it was obvious that the heat source using propane torch was not adequate to give uniform additional heat input in all welding phase and still need another more potent heat source in order to improve the performance.

Keywords: forces; friction; non-rotating shoulder tool; performance; stir welding

1. INTRODUCTION

Increasing demand for fuel efficiency and payload has become challenging factors for aircraft manufacturer and also automotive industry. Lighter construction of aircrafts and vehicles while still able to maintain good structural integrity become something sought after in both industries. In responding the challenge then the industries rely on aluminum alloys such as AA2024, 6061, 6063, 6082, 7075 and 8090 (1). Besides finding innovation in the material, they also cut time and cost of production, when it is possible improve mechanical properties of aircraft and vehicle structure (2). This make, riveting as a conventional method to joint parts of aircraft and vehicles is substitute by welding process.

Welding process by fusion method proved to have problems in form of slag inclusions, distortion, cracking on solidification, void in weld beads because of incompatibility between filler and base-metal, occurrence of aluminum oxide, hydrogen solution, etc. (3),(4),(5). One of potential methods in welding to minimize those problems are adopting Laser Beam Welding (LBW) and Friction Stir Welding (FSW) (6).

Especially for FSW process, since 1999 NASA already employed this process to joint outer fuel tank and becomes first application in aeronautics (7). Even tough the process is able to produce products with good repeatability, reliability and good in joining light metal alloy, it has drawback in set-up (need special clamping system), and only suitable to simple joint (butt-weld) and still need license from TWI as patent holders (6). From this drawbacks, the second one (versatility) of the welding process need to be addressed.

It is commonly known that structure of aircraft and vehicle is not a simple one due to many of its parts in form of curve (3 dimensional) so that restrict application of FSW. Another process, i.e. LBW, is considered prone to porosity, while the HAZ is so obvious even though welding speed and corrosion rate is considered in balance (2).

Ability to follow contour become one of the big problem because forces and torques generated in process is big and become something common the process utilize big machine tool. As consequence, the welding is limited to 2 dimension (2-D). In order to be able to follow 3 dimension (3-D) then it need special mechanical configuration and good control strategy to have capability in smooth 3-D path (8),(9),(10).

Using of special mechanical configuration for FSW machine is not become popular idea, especially for industry. Therefore, robotic manipulator become one of the solution in addressing the limitation in 3-D welding. To be able to use, the first thing needed to be solved is the problem associated with limitation in maximum load able to handle and perturbation during process. The problem of maximum loads can be solved by extend the work envelope thru work-cell layout setting and lowering load and torque generated during process. Then, perturbation can be solved thru designing proper controller (11).

In this works, lowering force and torque was pursued by using Non-rotating Shoulder Tool and using preheating from torch.

2. METHODS

Non-rotating Shoulder Tool (NRST) combined with the torch preheating was examined to lower the forces generated during FSW process and its joint. NRST is able to make sound weld by only using motion of the pin to stir and transport molten material to fill void left by pin (12). Due to the forces and torques are the function of area, then smaller one generates the lower force and torque. In addition, preheat lower the forces and torques further because it is softened then lowering the strength of aluminum or material.

2.1 FSW Machine

Designed FSW machine is illustrated in Figure 1. It consists of NRST, additional heat by propane torch, clamping system and force measuring devices. The control of rpm and traverse speed was done by setting particular machine tool able to perform automatic feeding. The forces was monitored thru 3 load cells to monitor F_z and F_x .

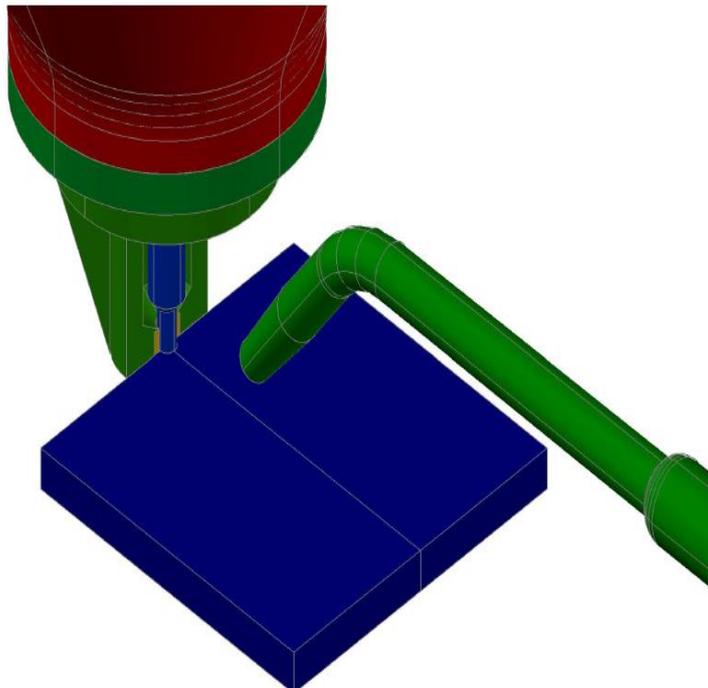


Figure 1. FSW machine

2.2 Specimens and Clamping

The specimens were Aluminum Alloy 2XXX cut to 100 x 200 mm with 6 mm thickness. The clamping system secure the work-piece during FSW process.

3. RESULTS AND DISCUSSION

3.1 Integrity of Welded Joint

The integrity of joints produced using NRST and Preheat were given in Figure 2.



a). $\omega = 950 \text{ rpm}$; $v = 67 \text{ mm/min}$, $d = 6,1 \text{ mm}$

b). $\omega = 950 \text{ rpm}$; $v = 110 \text{ mm/min}$, $d = 6,1 \text{ mm}$



c). $\omega = 1200 \text{ rpm}$; $v = 67 \text{ mm/min}$, $d = 6,1 \text{ mm}$

d). $\omega = 1200 \text{ rpm}$; $v = 110 \text{ mm/min}$, $d = 6,1 \text{ mm}$

Figure 2. Integrity of joints

From Figure 2, it was clear that the integrity of weld joints for 950 rpm was not so good. There were obvious unfilled regions on the advancing side of weld while for 1200 rpm even though it is still exists. But the size become smaller. The main reason for this phenomenon is the sound welding only produced when sufficient heat input is available in the process to sufficiently melt and transport material to fill void left by tool. When the heat input as the results of conversion of friction and strain around tool is sufficient, then the sound welding may be developed. But, when heat input is not sufficient, then the void or unfilled regions may exist.

The specimens then was cut to show the joint integrity and were presented in Table 1 and Figure 3.

Table 1. Assessment of weld

Speed ω (rpm)	Initial Temperature (300 °C)	
	$v = 110$ mm/min	$v = 67$ mm/min
950	Defect (void)	Defect (void)
1200	No defect	Defect (void)

Table 1 and Figure 3 show the quality of weld for certain variation of parameters. The only non-defect one was at parameter of 950 rpm and traverse speed for 110 mm/min. The other parameter variation produce void inside the weld zone. The possible causes for this condition is sufficiency of heat input and time to fill the void caused by tool. When the rotational speed was low, 950 rpm, then it was insufficient to generate enough the heat to produce sound weld. When the traverse speed was too high, 110 mm/min, then it was not enough material to transport in filling the void caused by tool. Therefore, it become clear that choosing right parameters affect the good quality of welds.

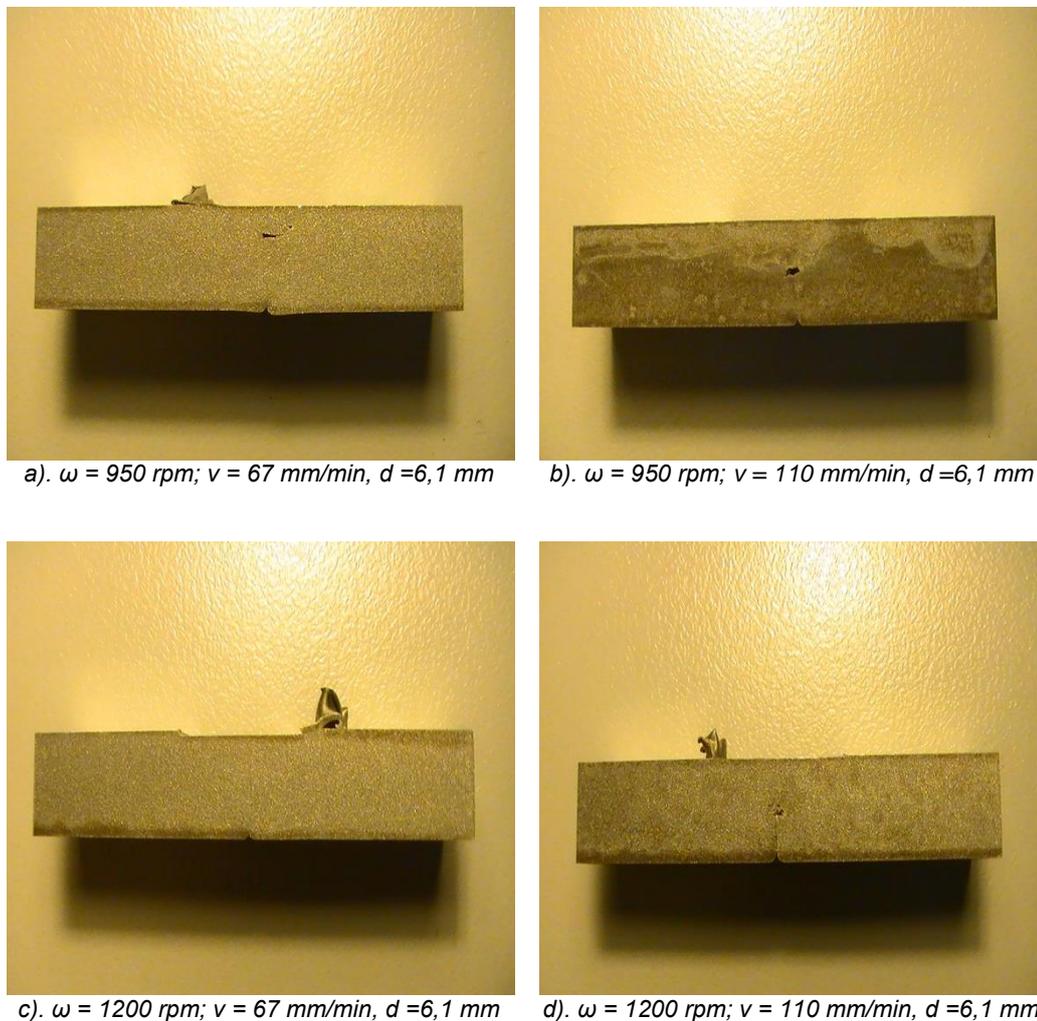


Figure 3. Shape of joint

3.2 Welding Forces

Force generated during several weld forces was presented in Table 2. The forces become lower when rotational speed or initial temperature (after additional heat) were increased. The lowest forces for x direction, F_x , for plunge stage was of 278.4 N while for welding stage was of 1601.4 N. Meanwhile, for plunge stage the lowest F_x was of 1720.3 N and for welding state was 2003.2 N. All the lowest value for forces was obtained for rotational speed of 1500 rpm. Higher initial temperature will make material strength lower and also higher rotational speed.

Table 2. Forces for Various Welding Parameters

ω (rpm)	ν (mm/min)	d (mm)	Initial Temp. (°C)	Plunge Stage		Welding Stage	
				F_x (N)	F_z (N)	F_x (N)	F_z (N)
950	110	6.1	Room	814.0	2568.5	2187.8	2742.0
950	110	6.1	300	320.0	2401.0	1968.8	2601.0
950	110	6.1	400	292.2	2150.9	1708.3	2556.1
1200	110	6.1	Room	790.3	2430.3	2095.3	2643.6
1200	110	6.1	300	290.5	1942.3	1897.3	2254.1
1200	110	6.1	400	281.5	1786.4	1643.8	2187.5
1500	110	6.1	Room	749.3	2401.9	1997.3	2601.4
1500	110	6.1	300	283.5	1889.7	1804.4	2197.5
1500	110	6.1	400	278.4	1720.3	1601.4	2003.2

Since decrease in welding forces after 300 °C is not significant, it is wise to not to increase initial temperature too high during oxidation and other chemical reaction may occurred.

3.2.1 Run 1 ($\omega = 950$, $\nu = 110$, $d = 6.1$, $T = 17^\circ\text{C} / \text{room}$)

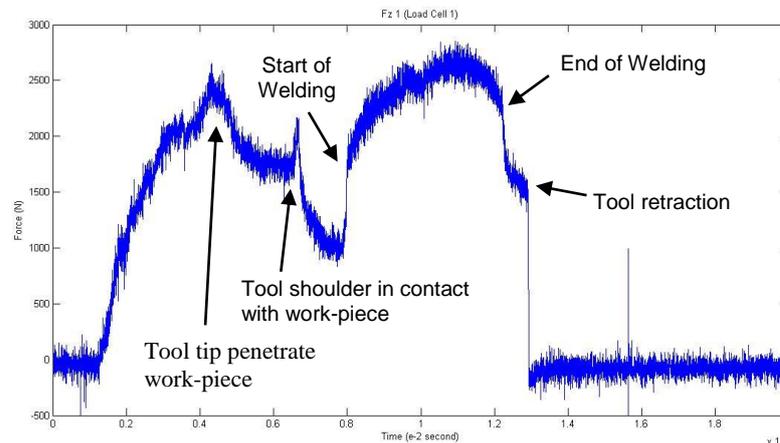


Figure 4. Force, F_z , for run 1

From Table 2, the significant force reduction was occurred on F_x , but F_z does not have significant force reduction. The main reason for this case is the additional heat source cannot maintain significant heat input when the weld started due to the transient behavior of heat source.

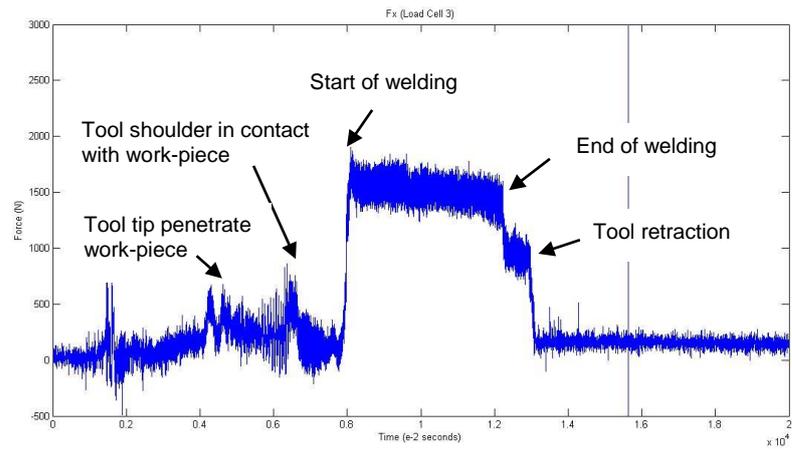


Figure 5. Force, F_x , for run 1

3.2.2 Run 2 ($\omega = 950$, $\nu = 110$, $d = 6.1$, $T = 300$ – Tool heated)

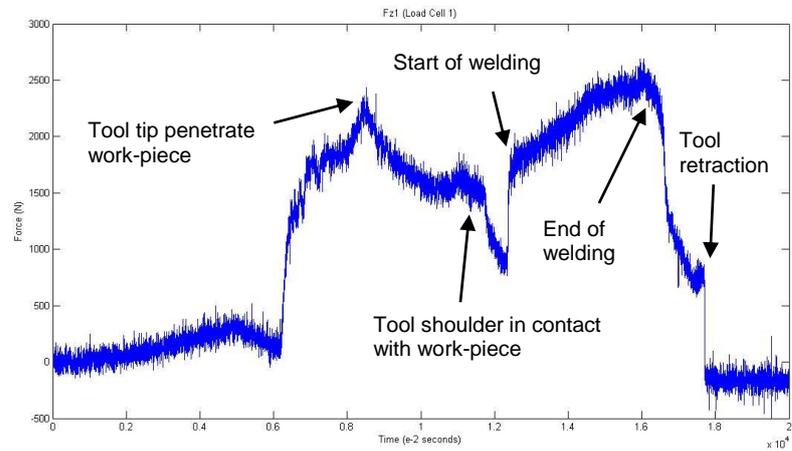


Figure 6. Force, F_z , for run 2

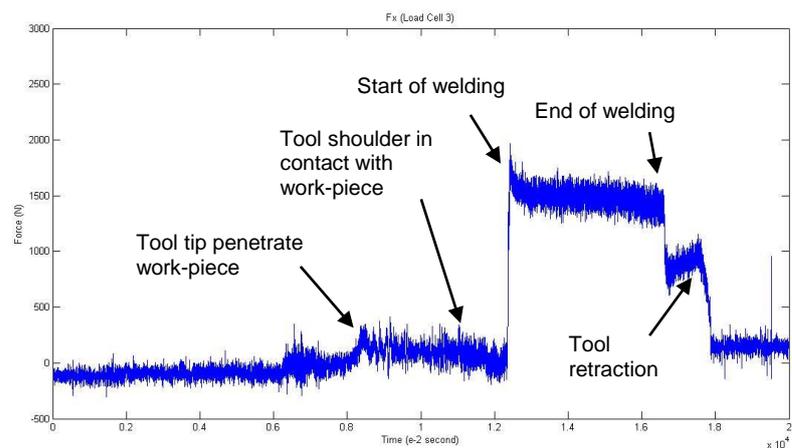


Figure 7. Force, F_x , for run 2

3.2.3 Run no 3 ($\omega = 950$, $\nu = 110$, $d = 6.1$, $T = 400$ – Tool heated)

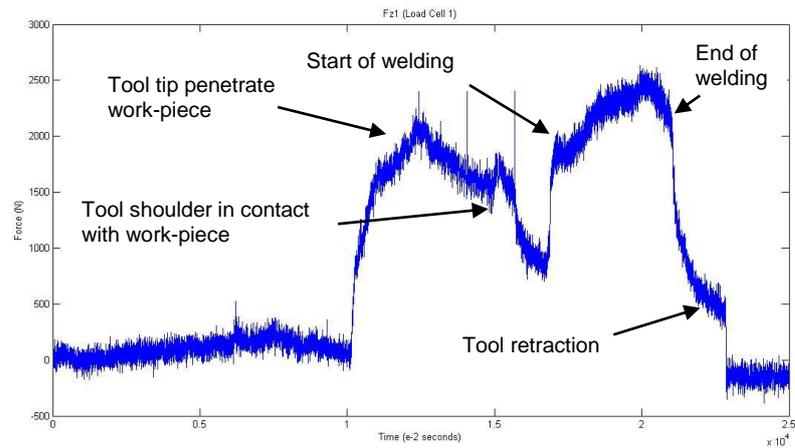


Figure 8. Force, F_z , for run 3

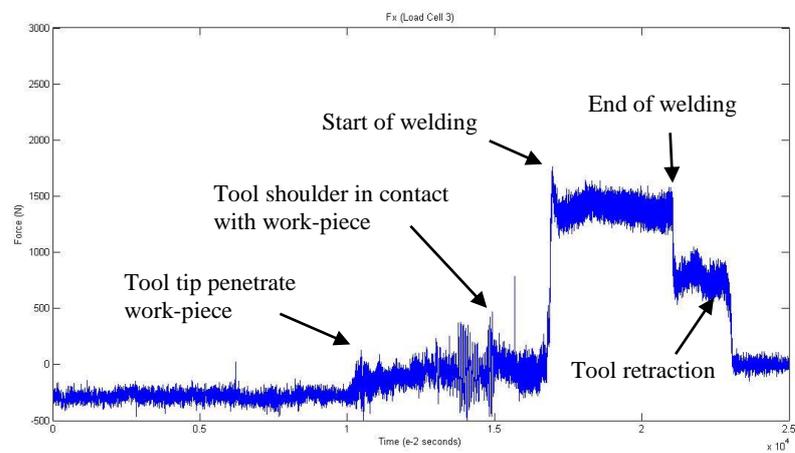


Figure 9. Force, F_x , for run 3

3.2.4 Run no 4 ($\omega = 950$, $\nu = 110$, $d = 6.1$, $T = 400$ – Tool heated)

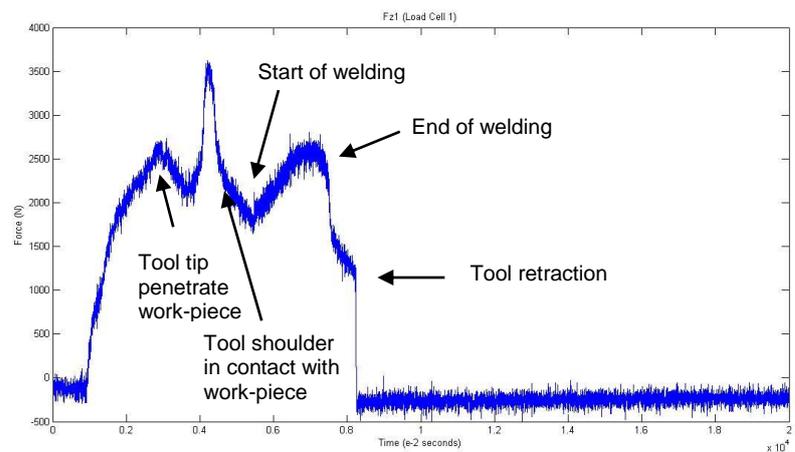


Figure 10. Force, F_z , for run 4

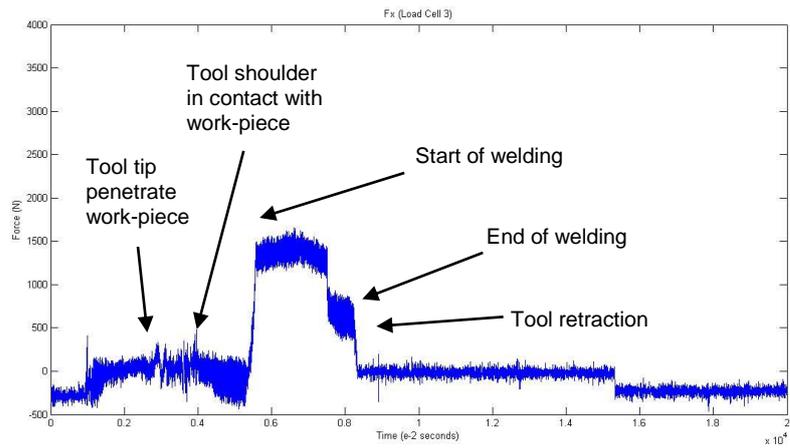


Figure 11. Force, F_x , for run 4

3.2.5 Run no 5 ($\omega = 950$, $\nu = 110$, $d = 6.1$, $T = 400$ – Tool heated)

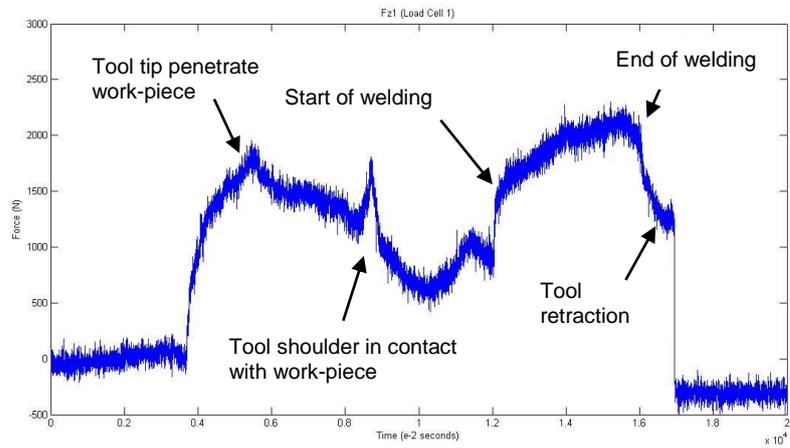


Figure 12. Force, F_z , for run 5

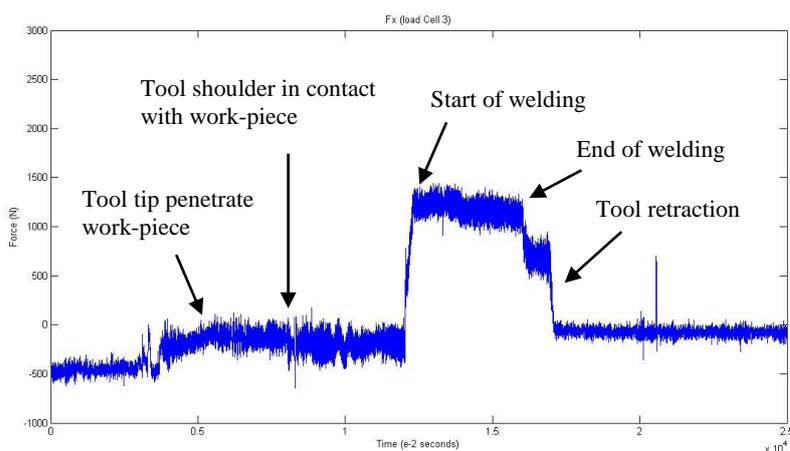


Figure 13. Force, F_x , for run 5

During welding, the patterns of Fz and Fx on all runs generally can be considered similar as presented in Figure 4 to Figure 13. When examining the pattern of Fz, it was shown that the forces is not stable as Fx. This is caused by heat source from propane torch cannot supply enough heat to keep the overall heat input. It runs together with friction from pin and high strain rate of material, shown in certain value to lower Fz as achieved at the start of the welding.

The pattern of Fx experienced small increased which may caused by rigidity of the test rig. The sudden drop at the end of welding before tool retraction was caused by the welding machine stop the transversal movement after certain welding length had been achieved.

4. CONCLUSIONS

From the discussion above, it can be concluded that in order to achieve sound welding, the parameters of welding need to be chosen properly. As explained in the discussion, when the parameters does properly chosen, then the heat input and availability of material to fill the void left by tool may cause weld defect.

The ability of the system to lower the forces only limited to Fx while Fz still show insignificant decrease. It is mainly caused by inability of the system to supply enough heat to make forces lower.

Even tough the system apparently have potent in lowering the forces, it still need more efficient additional heat input to make sure the decreasing of Fx and Fz can be maintained.

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