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OPTIMIZATION OF PROCESS PARAMETERS ON TENSILE SHEAR LOAD OF FRICTION STIR SPOT WELDED ALUMINUM ALLOY (AA5052-H112)

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Abstract -- *Optimization of the process was still the issue in manufacturing. Investigation on the process parameters that effects to the property of welded structure were necessary. In this study, the AA5052-H112 sheets of 2 mm thick were welded using friction stir spot welding (FSSW) and tested via tensile shear load test to investigate the influence of spindle speed, tool depth, and dwell time to the tensile shear load of the joints. The result shows that in every set of parameter combination, exhibit interesting influence to the tensile shear load. The effect of spindle speed of 1000 rpm showed the good property in average 18.33 kN especially at tool depth of 3.5 mm. Furthermore, the effect of tool depth brought significant effect to the tensile shear load especially at 3.5 mm for each set of spindle speeds and dwell times. The set of dwell time to parameter combination had no significant effect to the tensile shear load. The good tensile shear load could be achieved in the range of 3.5-3.9 kN at 3.5 mm of plunge depth and 1000 rpm of spindle speed, where the best one was 3.9 kN at 7s of dwell time.*

Keywords: *Friction stir spot welding; Tensile shear load; AA5052-H112*

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INTRODUCTION

In manufacturing especially in automotive industry reducing weight of a vehicle is a significant way to reduce fuel consumption. Application of lightweight materials in automotive has been rapidly growing since a decade. The most applied and developed lightweight material in industry is Aluminum. One of the common joining processes used in automotive is friction stir spot welding (FSSW) (Necdet et al., 2017). FSSW is the variant in friction stir welding (FSW), developed by The Welding Institute in the UK since 1991. Advantageous by using this technique among others are low distortion, low energy, and avoiding melt related defects. FSSW can be used to replace the technique of resistance spot welding (RSM) due to its poor weld consistency, short electrode tip life, and melt-related defect problems such as porosity, on joining automotive body part of aluminum alloy (Prayitno and Arsyad, 2018; Jeon et al., 2012).

According to the process of FSSW as shown in Fig. 1, the process consists of three main stages i.e. plunging, stirring, and retracting (Nguyen et al., 2011). The process begins with rotating the FSSW tool at a fix angular speed that set beforehand. During rotating, the tool then is forced onto the workpieces until the tool pin plunged into the workpiece, and ultimately shoulder contacts the top surface of the upper workpiece to form a weld spot. The plunging movement of the tool causes the softened material escape from its original position. However, the tool shoulder restricts the softened metal flow to the shoulder position. After plunging, the stirring stage starts when the tool reaches a predetermined depth. In this stage, the tool keeps rotating in the workpieces to generate heat (Chao et al., 2016). This heat mainly influenced by two actions, i.e. friction between rotating tool and workpiece, and severe plastic deformation of the workpiece (Hirasawa et al., 2010). Thus, the materials adjacent to the tool are heated, softened, and mixed in the stirring stage where a solid-state joining will be formed (Mishraa et al, 2005). Material around the tool is softened by friction heating and stirred by the tool to unify between both surfaces (Muhayat et al, 2014), (Padmanaban et al., 2014). The process is ended at the stage of retracting where the tool is slowly retracted from the workpiece back to the initial position.

Based on the process above, it can be seen that parameters from rotating, plunging and stirring play important role in producing weld. The problem was how far those parameters have significant effect to the property of the weld. Therefore, those parameters, such as rotating speed, plunge depth and dwell time, necessary to be investigated about their contribution to the mechanical property of the weld. Besides, optimization of the FSSW process via determination of the process parameters was also needed to produce the best weld (Piccinia and Svoboda, 2015a and 2015b).

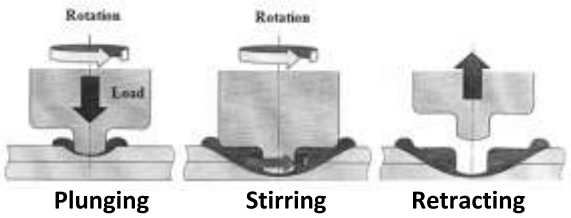

Figure 1. FSSW process applied on overlap join of Aluminum alloy workpieces (Awang et al., 2014)

The effect of the process parameters to mechanical property of the weld, such as the tensile shear load, was the main objective in this study. The best fit among those parameters' combination was also be researched.

MATERIAL AND METHOD

In this study the material used composed of the work pieces for experiment and test, and the FSSW tool for experiment. Those materials are prepared in a workshop beforehand. The methods for tensile shear load test in this study followed the JIS Z3136:1999 standard. The following was the detail about material and methodology.

Material

Material for work piece used for welding and testing in this study was Aluminum alloys AA5052-H112 due to commonly used in manufacturing especially in automotive car body (Kumbhar et al., 2012), (Venukumar et al., 2014). This alloy has a good strength, formability and corrosion resistance (Kwon, 2012). Even though Aluminum alloys have some disadvantages especially for welding. It is well known that Aluminum alloys show very poor weld ability compared to fusion welding due to local high temperature during welding that can produce undesirable deformation of sheet metal (Triyono et al., 2014). Table 1 shows the chemical composition of AA5052-H112.

With respect to the preliminary laboratory as depicted in Fig. 2, preparation on work pieces and FSSW tool were done. The dimension of the workpieces was 125 x 40 x 2 millimeters (mm) with overlap area of 40 x 40 mm according to the JIS Z3136:1999 standard, as shown in the Fig. 3.

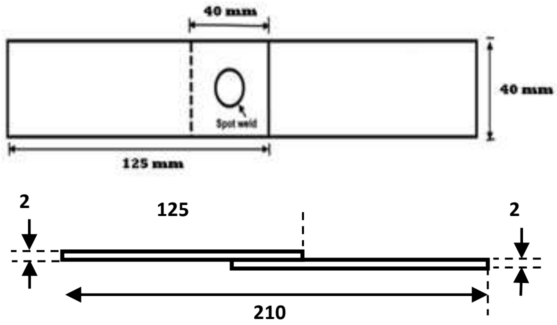

Figure 2. Geometry of mechanical test of specimen AA5052 H112, 2 mm thick in FSSW with overlap join.

Table 1. Chemical composition of AA-5052-H112 (mass fraction, %)

Cu	Mg	Si	Fe	Mn	Zn	Cr	Al
0.10	2.2	0.25	0.4	0.10	0.10	0.35	Bal

Material for FSSW tool in this study is K100 tool steel with 5 mm pin diameter and 2 mm pin length of cylindrical pin profile (Bahrami et al., 2014). Shoulder diameter was 12 mm. The geometry of FSSW tool is showed in Fig. 3.

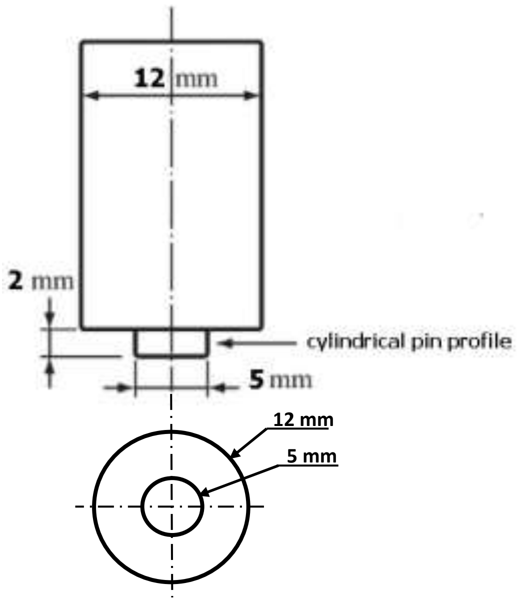

Figure 3. Geometry of FSSW tool with cylindrical pin profile.

Method

The welding experiment in FSSW was applied on the vertical head CNC milling machine (FIRST-MCV300) with the position perpendicular to the surface of the work piece as shown in Fig. 4. The work piece was firmly clamped to the bed and a FSSW tool was plunged into the spot weld of the work piece for sufficient time in order to plasticize around the pin. The parameter of FSSW process used in this study consisted of spindle speed, tool depth and tool dwell time. The spindle was set in the constant speed of 1000, 1200 and 1400 radian per minutes (rpm) respectively. In every set of spindle speed, the tool depth was arranged at 2.5, 3, and 3.5 mm respectively. Furthermore, for every state of tool depth, the tool dwell time was varied from 5, 7, and 9 second (s). From such setting it was formed 27 combinations among those three parameters for FSSW that applied for each sample work piece (Table 2). This was planned in such a way to investigate any changes of load occurred as a result of changes the parameter combination during FSSW.

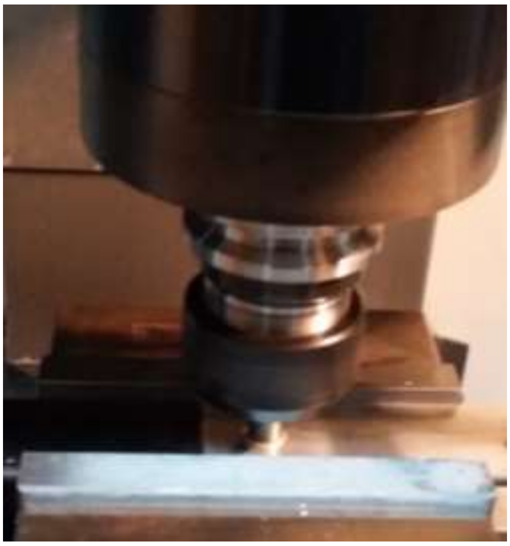

Figure 4. FSSW using vertical head CNC Milling machine with the position of the tool that perpendicular to the work piece surface.

After FSSW process the sample of specimen where joined in overlap form were collected according to the 27 set of parameter combination. Each set of parameter combination had 3 samples of specimens for testing where all sample in total were 81 samples of specimens. The Fig. 5 shown the sample of specimen used for tensile shear load test.

Figure 5. FSSW sample of specimen after welding that ready for tensile shear load test.

Furthermore, the method being used for testing in this study was tensile shear load test that is used commonly for sheet metal testing under JIS Z3136:1999 standard. Tensile shear load test was performed under a cross head speed of 1 mm/s according to the JIS Z3136:1999 standard. The room temperature of the friction stir spot welding sheet was evaluated by conducting tensile shear load test on a 100 KN Instron universal testing machine as shown in Fig. 6.

Figure 6. Tensile shear load test on a 100 kN Instron universal testing machine.

The workflow of this method depicted in the Fig. 7. First of all, preliminary laboratory which consisted of preparation on the workpiece for FSSW and testing as well as FSSW tool and JIG had to be done. After that FSSW experiment was performed using CNC Milling machine to the work pieces for making the sample of specimen for testing by using 27 set of parameter combination. Then each sample of specimen was tested mechanically using tensile shear load test at room temperature until produced the data of load. Furthermore, those data were analyzed and investigate to determine the significant effect to the load with respect to the parameter combination installed during FSSW process. Finally, the maximum load and the effect to the tensile shear load, as well as the best fit, have to be determined for 2 mm thick AA5052-H112 material alloy.

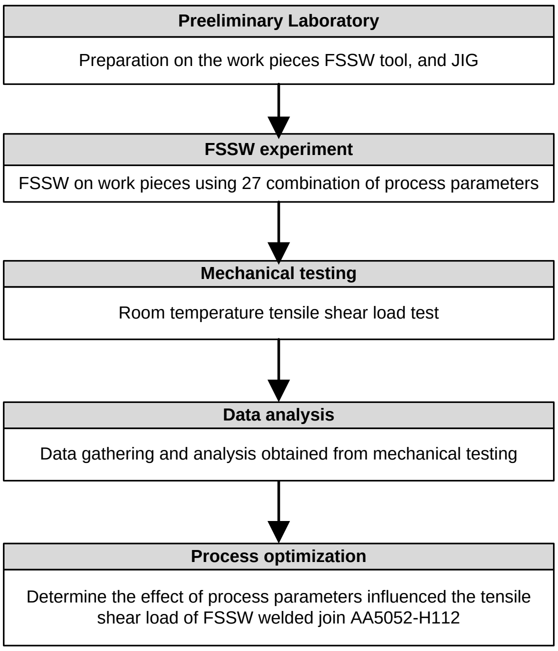

Figure 7. Workflow of the study

RESULTS AND DISCUSSION

FSSW experiment and tensile shear load test for AA5052-H112, 2 mm thick, overlap join had been completely done. In this section the data obtain from the experiment and test would be analyzed especially from 27 set of parameter combinations consisted of spindle speed, tool depth and dwell time as listed in Table 2.

From the result shown in Fig. 8, the tensile shear load at spindle speed of 1000 rpm, it could be seen that the loads fluctuated unregularly in the range of 1.2 kilo Newton (kN) up to 3.9 kN, by set of dwell time from 5s to 9s, for 2.5, 3, and 3.5 mm of tool depth respectively.

Table 2. Experimental results of tensile shear load test

Spindle speed (Rpm)	Tooldepth (mm)	Dwell time (s)	Mean Tensile shear load (KN)
1000	2.5	5	1.28
1000	2.5	7	1.16
1000	2.5	9	1.32
1000	3	5	1.8
1000	3	7	2.49
1000	3	9	2.45
1000	3.5	5	3.6
1000	3.5	7	3.86
1000	3.5	9	3.53
1200	2.5	5	1.12
1200	2.5	7	1.23
1200	2.5	9	1.1
1200	3	5	1.6
1200	3	7	1.5
1200	3	9	1.5
1200	3.5	5	2.5
1200	3.5	7	2.23
1200	3.5	9	2.87
1400	2.5	5	1.2
1400	2.5	7	1.1
1400	2.5	9	1.26
1400	3	5	1.75
1400	3	7	1.89
1400	3	9	1.84
1400	3.5	5	3.53
1400	3.5	7	2.9
1400	3.5	9	3.12

The good load achieved by 3.5 mm of tool depth from 3.6 to 3.9 kN. The middle load occurred between 1.8 and 2.5 kN by 3 mm of tool depth. The lower load reached around 1.2 – 1.3 kN by 2.5 mm of tool depth. From this result it can be clearly seen that for 1000 rpm of spindle speed, the increasing of tool depth from 2.5 mm until 3.5 mm, increased the tensile shear load with the higher load up to 3.9 kN by set of parameter combination at 3.5 tool depth and 7s of dwell time.

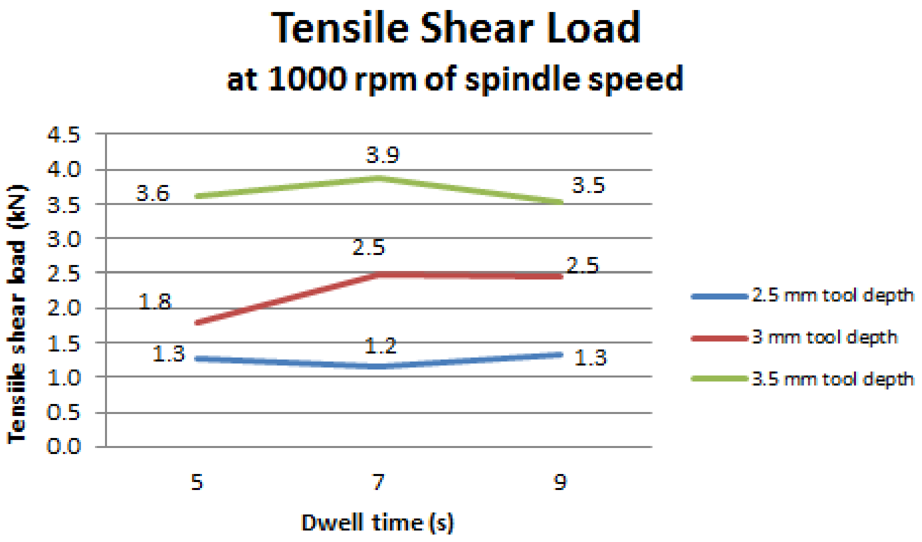

Figure 8. The result obtained from the tensile shear load test with 1000 rpm spindle speed for 2.5, 3, and 3.5 mm of tool depth by set of dwell time 5, 7, and 9 second.

Furthermore, the tensile shear load with 1400 rpm of spindle speed, shown the unregularly result varied from 1.1 to 3.5 kN by set of dwell time from 5s to 9s as shown in Fig. 10. This variation of load occurred in all set of tool depth 2.5, 3, and 3.5 mm. The good loads were varied in range of 2.9-3.5 kN by set of 3.5 mm of tool depth along the set of dwell time (5s-9s). The middle loads occurred uncertainty between 1.8 and 1.9 kN by set of 3 mm of tool depth. The lower loads were reached around 1.1 – 1.3 kN by set of tool depth at 2.5 mm. From this result exhibited that at 1400 rpm of spindle speed, with the increasing of tool depth from 2.5 mm until 3.5 mm, increased the tensile shear load with the higher load up to 3.5 kN by set of parameter combination at 3.5 tool depth and 5s of dwell time.

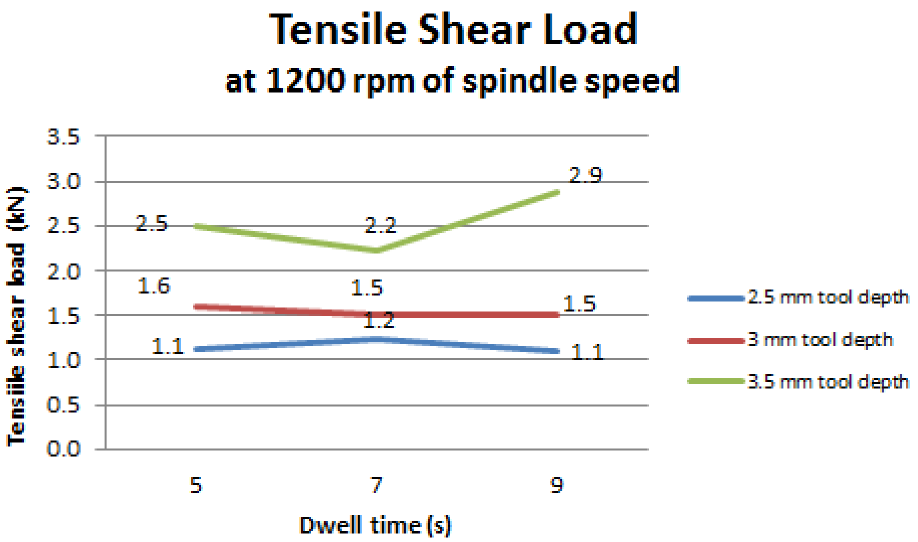

Figure 9. The result obtained from the tensile shear load test with 1200 rpm spindle speed for 2.5, 3, and 3.5 mm of tool depth by set of dwell time 5, 7, and 9 second.

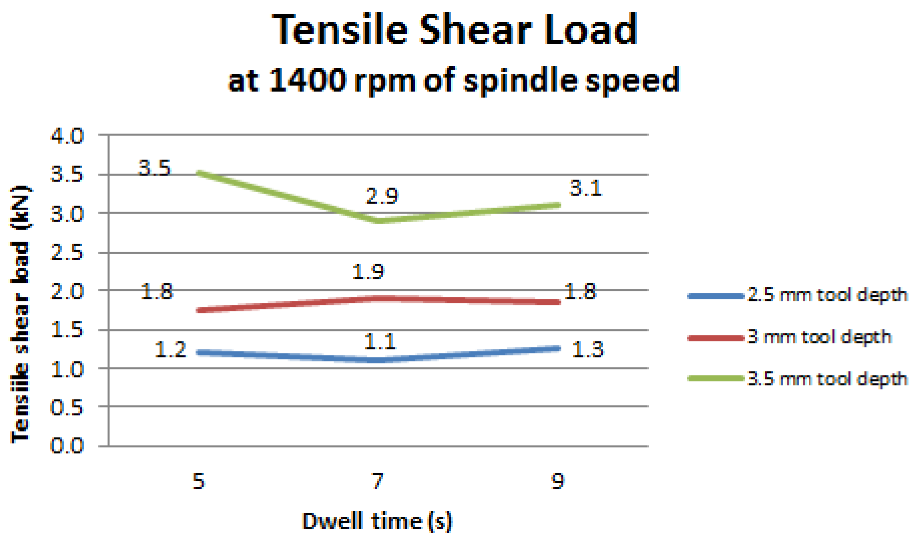

Figure 10. The result obtained from the tensile shear load test with 1400 rpm spindle speed for 2.5, 3, and 3.5 mm of tool depth by set of dwell time 5, 7, and 9 second.

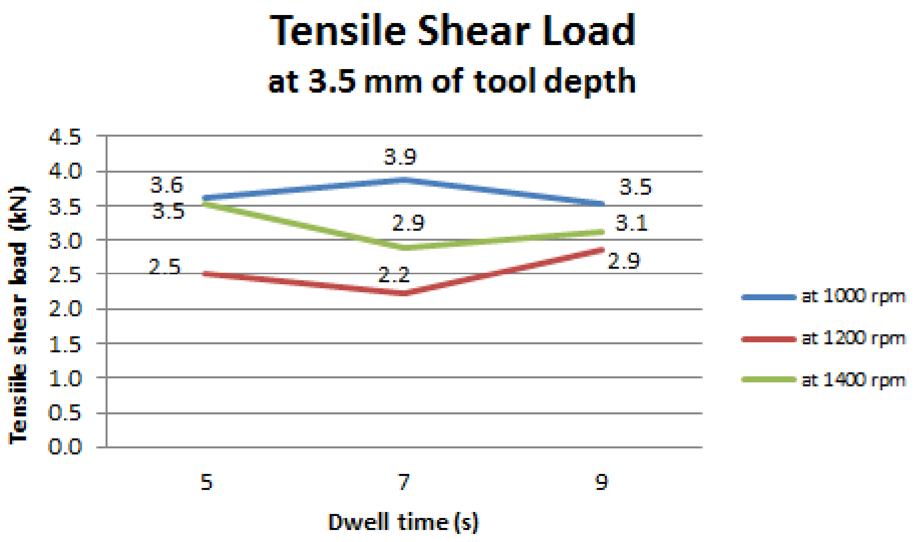

Figure 11. Comparison of the tensile shear load at 3.5 mm tool depth to the set of spindle speed and dwell time.

From the result above it can be seen clearly that for every set of spindle speed, the set of 3.5 mm tool depth, brought the highest tensile shear load compared to other set of tool depths (2.5 mm and 3 mm). The loads were varied uncertainty along the set of dwell time from 5s to 9s for each set of spindle speed. From the Fig. 11, it can be seen that at 1000 rpm achieved the highest value compared to other spindle speeds. The middle value of loads was represented by 1400 rpm and the lower value by 1200 rpm, where occurred unregularly along the set of dwell time.

CONCLUSION

This study was focused on the effect of the process parameters (spindle speed, tool depth, and dwell time) in FSSW with respect to the tensile shear load under JIS Z3136:1999 standard. Investigation was successfully done through experiment and test on sample specimens of 2 mm thick overlap join of AA5052-H32. The parameters were setted up in such away into 27 set of parameter combinations and applied on the samples of specimens. Furthermore those sample of specimens were tested via tensile shear load test. The result shown that in every set of parameter combination exhibit interesting influence to the tensile shear load.

For 1000 rpm represented the highest load of 3.9 kN. At 1200 rpm and 1400 rpm reached the maximum loads of 14.4 kN, and 6.3 kN respectively. These high of loads were mainly due to the farthest tool depth at 3.5 mm. This was aligned with the statements that, the fracture loads increased with the tool penetration depth (Puccinia et al, 2015), (Muhayat et al, 2014). However, the loads were fluctuated unregularly in every set of speed if the parameter combination installed with the dwell time from 5s to 9s.

Therefore it was concluded that in the set of parameter combination among spindle speed, tool depth and dwell time in FSSW of 2 mm thick AA5052-H112, tool depth brought the significant effect to the tensile shear load. Increasing of the tool depth meant increasing of the tensile shear load. The highest level of load could be achieved with the set of 3.5 mm tool depth. The good tensile shear load of 2 mm thick AA5052-H112 in friction stir spot welded structure could be achieved by set of parameter combination at 1000 rpm of spindle speed, 3.5 mm of tool depth, and 7s of dwell time with max tensile shear load of 3.9 kN.

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