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Design and Development of Stirring Tool Pin Profile for Reconfigured Milling Machine to Perform Friction Stir Welding Process

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Design and Development of Stirring Tool Pin Profile for Reconfigured Milling Machine to Perform Friction Stir Welding Process

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Abstract. Three customized stirring tool pin profiles have been designed which are (1) straight cylinder, (2) triangle shape, and (3) tapered shape to be used by reconfigured milling machine (Cheng Yin – CY-GH 260) to perform friction stir welding process. Shoulder geometry is constant for all tools (20 mm having 8 deg concave and length of the pin from shoulder is 2.7 mm). Then, all the tools were fabricated and tested by joining two similar plates of Al 6061 and Al 7075. The tools are made of H13 steel (chromium-molybdenum). Welding parameter used are 1270 RPM for rotating speed and 218 mm/min for welding speed. The samples produced were evaluated based on physical appearance of weldment, tensile strength value, surface roughness value, and physical tool wear. From the result, all the designed and fabricated tool pin profiles were able to perform FSW successfully using reconfigured milling machine. Tapered tool produced the highest tensile strength with 134.95 MPa. However, straight cylinder tool produced smoothest surface roughness with 1.850 µm which provide better surface finish. Weldability of Al 6061 is better compared to Al 7075.

1. Introduction

Friction stir welding (FSW) is a solid-state joining process that uses a non-consumable tool to join two facing workpieces without melting the workpiece material. Heat is generated by friction between the rotating tool and the workpiece material, which leads to a softened region near the FSW tool. This technique was founded by The Welding Institute (TWI) of UK was the first agency that invented and developed FSW in 1991 [1]. The purpose of this welding was to join two similar metal or dissimilar metal that are difficult or impossible to join together for example the Al 6061 and copper for dissimilar joint [2] or Al 6061 and Al 6061 for similar joint [4]. There are no filler materials and shielding gas were used throughout the process [4].

One of the important component in FSW is stirring tool. The tool consists of elements such as pin and shoulder that is rotated and travelled at certain speeds, which subsequently produces plastic deformation due to intense friction under the shoulder. The deformed material inside the shoulder is swirled by pin and lead to the joint as tool is travelled [4,5]. Hence, the tool pin profiles affect material flow, plastic deformation and temperature variation that consequently influences the properties of the joint. The different of geometry tool pin profiles such as cylindrical, triflute, trivex, conical, triangular, square, pentagonal, hexagonal, octagonal, thread-less and with threads have been discussed in the literatures for different FSW systems [4]. Optimum pin profile depends on type of materials and the thickness of materials. Different materials such as Al, Cu, Ti, Mg, steel and plastics can be welded by FSW.

Defects are still occurs during the welding process mostly involving the designed tools pin profile like flash effect, surface tunnel, voids, pore and crack. Many research have been conducted to solve these defects by using a few varieties of geometric like cylindrical tool pin profiles, polygonal tool pin profiles and put thread by a few shape. The polygonal pin profiles were caused the defects like voids, fragmental defects and crack and the defects were decreased as the polygonal edges increases [2].

Based on the above fact, tool pin profile play an important roles in FSW process as it will act as a stirring agent to make a better welding process during the stirring and prevent the defects from occurring. Therefore, a proper and careful consideration must be made during designing the tool pin profile in order to get a better surface finish, better stirring during the welding and strength of the weldment. In this work, newly design of suitable tool pin profile that fulfill all the required criteria has been developed dedicated for reconfigured milling machine Cheng Yin – CY-GH 260 to perform FSW. Appropriate testing was conducted to evaluate the performance of newly designed tool.

2. Methodology

2.1 Design of stirring tool pin profile

In FSW, stirring tool consist of shoulder and pin. The functional requirement of the pin is to rub and stir two mating material to generate plastic deformation region. Then, the pin requires to stir to produce bonding across mating area while transporting material to the position behind the tool. From the identified tool pin functional requirements, three types of tool pin profile have been custom designed for reconfigured milling machine (Cheng Yin – CY-GH 260) to performed FSW. Figure 1 shows the design of stirring tool pin profile.

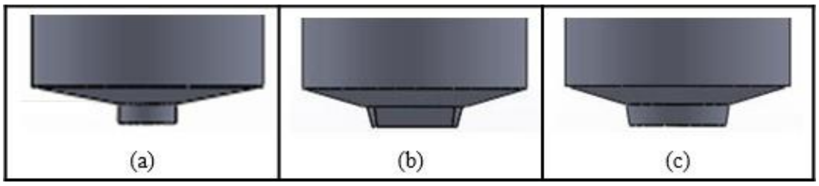

Figure 1. Design of stirring tool pin profile (a) Straight cylinder, (b) Triangle shape, (c) Tapered shape

2.2 Fabrication of stirring tool profile

All the designed stirring tool were fabricated using H13 steel. Conventional lathe machine is used to produce the tools and being heat treated. Figure 2 shows the fabricated tools.

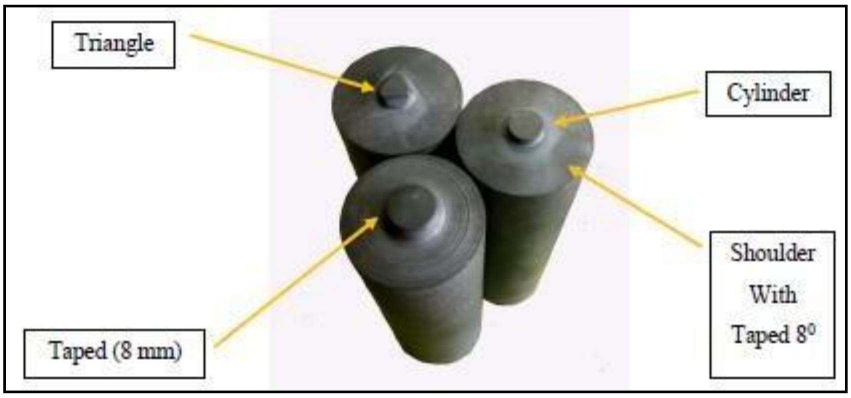

Figure 2. Fabricated tools

2.3 Design verification

For design verification, all the tools were tested to performed FSW process. Reconfigured milling machine was set-up to perform the experiments. Table 1 shows welding parameters used in testing the performance of newly developed stirring tool pin profiles. Rotational speed and welding speed has been set constant for easy evaluation. After the welding process, the weldment had been left for one month for natural ageing process before conduct tensile test. Figure 3 shows the setup of the tool pin profile to performed FSW process using reconfigured milling machine.

Table 1. Welding parameters

Stirring tool pin profile	Material	Rotational Speed (RPM)	Welding Speed (mm/min)
Tool 1: Cylinder	AA6061	1270	218
	AA7075	1270	218
Tool 2: Triangle	AA6061	1270	218
	AA7075	1270	218
Tool 3: Taped	AA6061	1270	218
	AA7075	1270	218

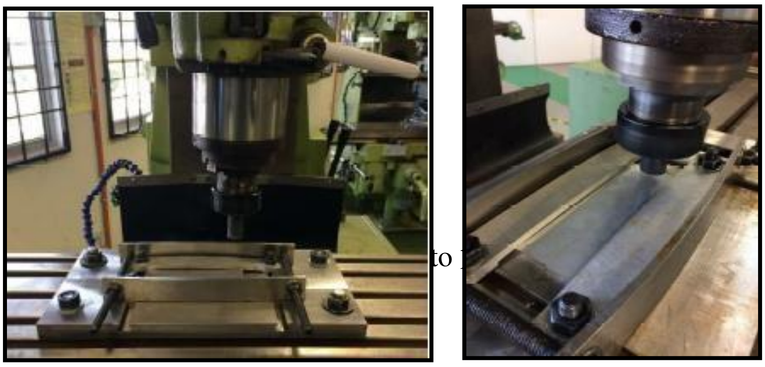

Figure 3. Setup of tool pin profile to performed FSW process

2.4 Design evaluation

For design evaluation, the samples produced from FSW are tested and compared for its physical appearance of sample, strength, surface roughness, and physical of tool wear. For physical appearance of sample and physical appearance of tool wear, the picture of weldment is captured using low power microscope. For strength, the samples were tested using 50kN universal testing machine. For surface roughness, Mitutoyo surface roughness tester (SURFTEST SJ-210) is used.

3. Results and Discussion

3.1 Physical appearance of samples

Table 2 shows physical appearance of weldment. From the result, it shows that all the fabricated stirring tool pin profile (cylinder, triangle, and tapered) for reconfigured milling machine are able to produce a FSW weldment. For all tools, material Al 6061 produce a greater appearance and defect free compared to sample of material Al 7075. In-complete weldment has been found in samples of Al 7075. It shows that weldability of 6xxx series alloy is greater than 7xxx series alloy. This is because, 6xxx series alloys is less resistances to deformation compared to aluminium 7xxx series alloys.

Table 2. Physical appearance of weldment from FSW

Stirring tool pin profile	Result
Cylinder	 Material: Al 6061  Material: Al 7071
Triangle	 Material: Al 6061  Material: Al 7075
Tapered	 Material: Al 6061  Material: Al 7075

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3.2 Welding strength

Tensile test was performed to obtain the ultimate tensile strength of the weldment of each sample. The strength value was measured at three different places which are at (1) started zone of tool penetration, (2) at middle zone and (3) at the end zone of the weldment. Figure 5 shows the tensile test result of all designed tools pin profile and the based metal (Al 6061). From the graph pattern, the started zone shown the lowest UTS was 89.68 MPa (Taped) while the highest UTS was 156.61 MPa (Triangle). The pattern was changed drastically during the middle zone about 122.03 MPa (Cylinder) the lowest UTS and 174.27 MPa for the highest UTS because of the quality the weldment during the stirring of the pin profile between two plate materials combination together. At the end zone, the lowest UTS was 88.78 MPa (Triangle) which the highest UTS was still taped design about 140.91 MPa but the value of UTS have been decreased from the middle zone because have a pin at that zone.

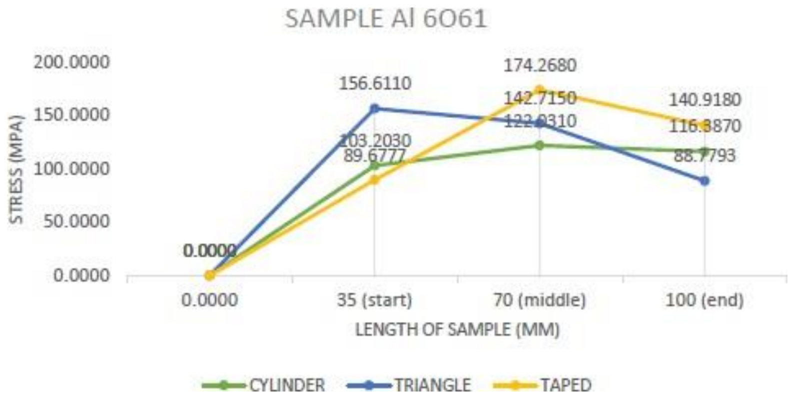

Figure 4. Tensile strength of sample Al 6061

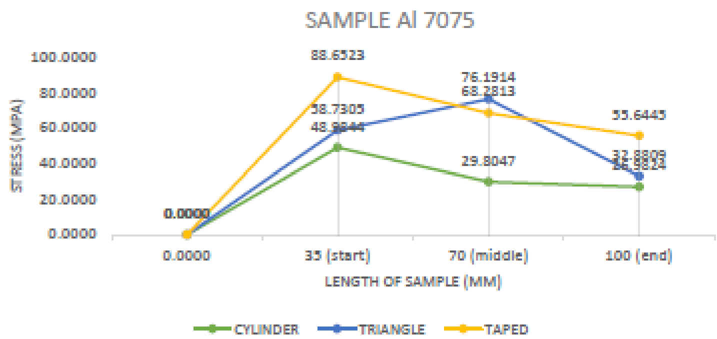

Figure 5. Tensile strength of sample Al 7075

Figure 6 shows the tensile test result of all designed tools pin profile and the based metal (Al 7075). From the graph pattern, the started zone have shown the lowest UTS was 48.98 MPa (Cylinder) while the highest UTS was 88.65 MPa (Taped). At the middle zone, the highest UTS's value was changed from the taped designed to the triangle designed while the lowest UTS was still cylinder designed about 29.80MPa. The end zone show the value of UTS was decreased because the pin has occur at the end zone was one of factor. The lowest UTS was 26.98 MPa (Cylinder) which the highest UTS was taped design about 55.64 MPa. As a conclusion, sample AA6061 was more suitable to perform in FSW process compare to sample Al 7075 based on the UTS value. From the result, the ultimate tensile strength's value for all three designed tools pin profile for the sample AA 7075 are low compared to sample Al 6061. The optimum ultimate tensile test value for this study was 134.95 MPa for sample Al 6061 that presented by taped pin to perform the FSW process.

3.3 Surface roughness

The surface roughness of the samples were measured at three different places which are at (1) started zone of tool penetration, (2) at middle zone and (3) at the end zone of the weldment. The measurement at each zone were taken three times to obtain the average reading for surface roughness of the specimens. Figure 7 and Figure 8 show the result of surface roughness for samples Al 6061 and Al 7075 at each zone. The started zone of the sample was mark as 35 mm for first length of sample, middle zone as 70 mm for second length of sample, and end zone as 100 mm for last length of sample.

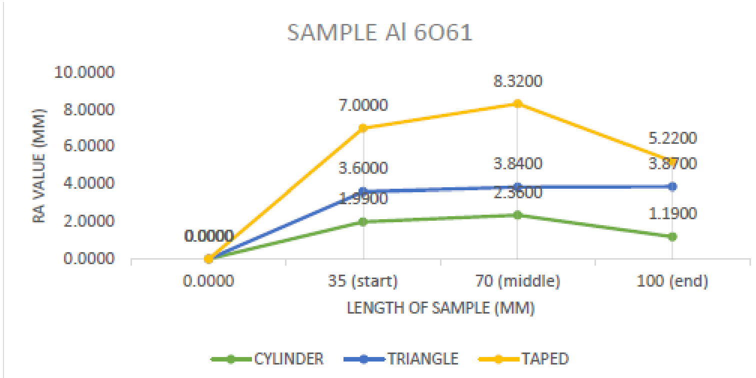

Figure 6. Surface roughness of Al 6061

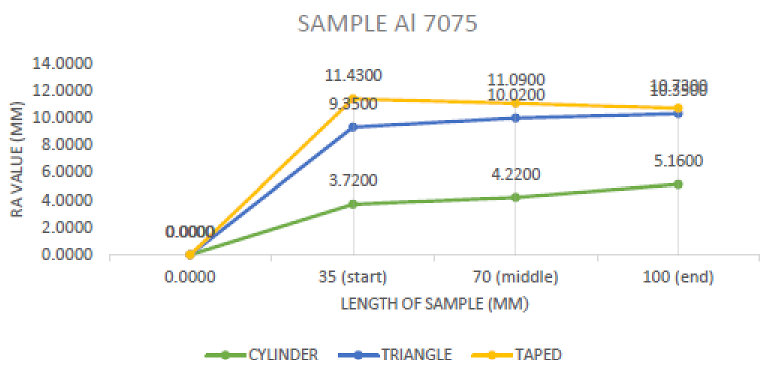

Figure 7. Surface roughness of Al 7075

Based on Figure 7, the taped's tool produced a highest surface roughness along the weldment (8.32 µm) at the middle zone. The lowest surface roughness along the weldment about (1.19 µm) at the end zone was the cylinder's tool. At starting zone of the process produce the less rough compare to the middle zone because of the combination cold zone and hot zone that can produced the rough surface during the FSW process. However, at end zone of FSW process, the roughness became lower again because of the sample's material became hot at that time and produced a better surface finish.

In Figure 8, the pattern of graph shown different with the graph of the sample Al 6061 while the taped's tool produced a highest surface roughness along the weldment (11.43 µm) at the start zone. The lowest surface roughness along the weldment about (3.72 µm) at the start zone was the cylinder's tool. At the starting zone of the process produce the less rough for cylinder and triangle's tool compare to the middle zone because of the combination cold zone and hot zone that can produced the rough surface during the FSW process while the taped's tool was high rough at started zone and less rough at middle because during the started zone the material of sample Al 7075 was hard then sample Al 6061 to melt during the FSW process. However, at end zone of FSW process, the roughness became high for the cylinder and triangle's tool because the material hard and take time to melt during the FSW process. While, the taped's tool became less rough again at end zone because of the sample's material became hot at that time and produced a better surface finish.

Besides that, the pattern of the surface roughness of the samples can be determine by analyzing the data and graph. The data and graph shown that for the sample Al 6061, the surface roughness for cylinder pin and taped pin of sample at the started zone and end zone of the weldment were the weakest compared to the surface roughness of the samples at the middle zone. This pattern was happen because during the started zone, the plate was start to produced hot zone to melt the material during the weldment process while the end zone has weakless ultimate tensile test value because has a pin at that zone. But for the triangle tool was different that pattern of graph and data represented the started zone have a lowest surface roughness because during the weldment process the triangle pin was produced the hot zone quickly than other because the triangle pin has a polygonal shape but increased by zone because of the combination of the hot zone and cold zone during the FSW process.

3.4 Physical tool wear

Figure 9 until Figure 11 shows a physical appearance of tool wear. From the results, it shows that the tool is not severely affected from the process performed. The structure of the pin profile is not damaged and can be further used to perform FSW in future. However, the colour of the tools is changing a bit due to continuously heat received during the process.

Figure 8. Physical appearance of tool wear for cylinder tool

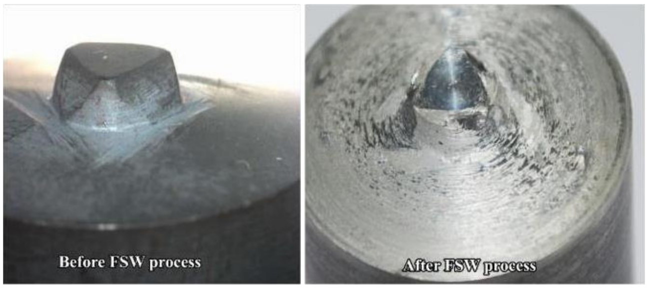

Figure 9. Physical appearance of tool wear for triangle tool

Figure 10. Physical appearance of tool wear for tapered tool

4. Conclusions

Three designed tools pin profile made of H13 steel were used for milling machine to perform FSW process. The fabricated three designed tools pin profile are successfully able to perform the FSW process by using milling machine. Tapered tool produced the highest tensile strength with 134.95 MPa while straight cylinder tool produced smoothest surface roughness with 1.85 µm which provide better surface finish. Weldability of Al 6061 is found better compared to Al 7075. Further study should be carried out to evaluate the performance of custom design of tool pin profile for reconfigured milling machine such as the effect of rotational speed and welding speed.

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