Investigation on the Effect of Varied Machining Parameters during Friction Stir Processing on the Effectiveness of Coating Al6061 on Mg Alloy

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Abstract. Friction Stir Processing (FSP) applies the same technique bases as Friction Stir Welding (FSW) however, instead of joining samples together, the technique modifies the local microstructure of consistent specimens to accomplish precisely and desired properties by surface-modifying the microstructure. As in FSW, the tool prompts plastic deformation during the technique, but rely upon on the selection of system parameters, that is applied enforcement, transverse speed and rotational speed to the performance or specification of the material. In friction processing, the high temperature requested to develop the technique is set up by friction heating at the interface. The cylindrical tool is fitted in a chuck started by a motor that is rotated at high velocity against the work piece which is fitted static. This stress is widened and contacting resistance develops heat to boost the areas to the welding temperature. In this study, varied machining parameters are applied for FSP process. The material selection in this study is based on the specification from the researchers which is using Mg alloy block and Al6061 as a coating on the Mg alloy block. The samples after FSP will be evaluate using hardness and microstructure testing. Furthermore, tests utilizing Brinell Hardness Tester and 3D Measuring Laser Microscope are conducted to further clarify the results by determining high toughness and fine grain structure. From this finding, Friction Stir Processing can upgrade properties such as durability, hardness, corrosion resistance, ductility, and formability without changing the bulk properties of the material.

INTRODUCTION

Friction Stir Processing (FSP) is a novel surface altering method that gives microstructural adjustment and control in the near-surface layer of metal parts [1]. FSP gives the ability to thermomechanical process particular areas on the structure's surface and to some considerable depth to enhance specific properties. FSP was developed based on the essential ideas of Friction Stir Welding (solid-state welding process) [2-4]. Essential parameters that are transverse speed (v) and the rotational speed of tool (ω) have a relation with the the pin and shoulder diameter which guarantees the results of friction stir processing on the workpiece during FSP [5-6]. Friction stir processing is a unique method to improve the microstructure in the strong state by utilizing the warmth from erosion [7-8] for the Mg alloy with coating Al6061. The coating Al6061, 6061 is usually utilized for the development of aircraft structures, more commonly in-homebuilt aircraft than commercial or military aircraft. 6061 is all the more effectively worked and remains resistant to erosion notwithstanding when the surface is rubbed [9]. Through this advanced world, there are some other time for substances having light-weight applications. In-car businesses, there are an enormous activity in light-weight materials. In the previous scarcely any years, aluminium combos have been the promising substances utilized for weight limit in vehicles [10]. Lately, magnesium combinations have been progressively utilized for weight reduction on account of their low thickness contrasted with aluminium alloys [11]. Magnesium alloys have pulled in expanding enthusiasm for transport vehicle fabricating because they can give an impressive weight decrease to structures [12]. Notwithstanding, their poor pliability, because of the predetermined number of slip frameworks accessible in the hexagonal structure at room temperature, could constrain their more extensive application [13]. FSP locally takes out natural throwing surrenders and significantly refines the grain framework, consequently upgrade properties of solidarity, malleability, elastic and so forth. The impact of friction stir processing on microstructure of magnesium alloy AZ91 and saw that extra grain refinement and homogenization when contrasted with the forged properties [14]. In order to achieve the necessitated surface modification with coating, several guidelines need to be encountered, hence the objectives for this study are to investigate the effect using varied parameters, and then determine the hardness and the fine-grain refinement of coating performance Al6061 on the Mg alloy block.

METHODOLOGY

The material used as the tool is H-13. Apart from that, the magnesium alloy block used is AZ91. The magnesium was cut into square-shaped for running three variation parameters on it, where different spindle speed and same transverse speed implemented for the three blocks. So, there will be 9 samples in total. For the coating on Mg alloy, Al6061 was used with thickness of 1 mm. The Al6061 will be placed on the Mg alloy block after bend. Then, the combined workpiece was clamped on the CNC milling machine to run the FSP process.

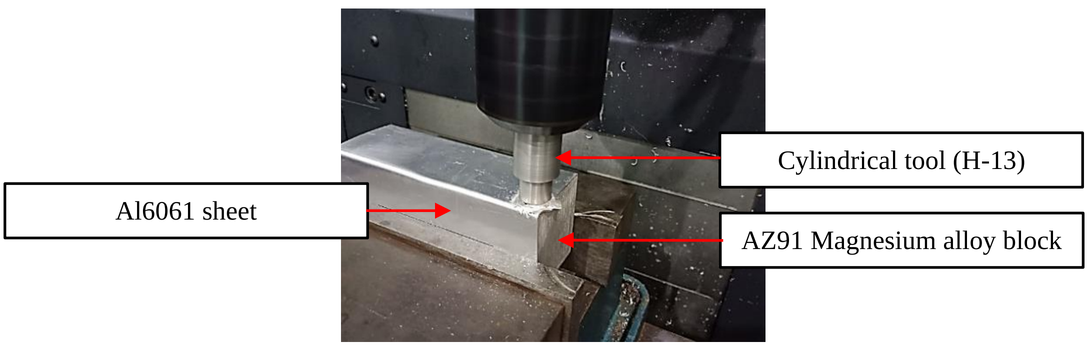


FIGURE 1. FSP operation using CNC Milling machine.

The Mg alloy block was cut into three parts with dimension of 50 mm x 50 mm x 50 mm for each block. The Al6061 with the thickness of 1 mm was used as coating on Mg alloy block and then cut into dimension same as Mg alloy block. By using the Vertical Band Saw machine, the Mg alloy block were cut. Facing process on each surface need to be done utilizing the CNC Milling machine to ensure be all surfaces were flattened. The coating Al6061 with 1 mm thickness was bend using a Bending Machine. The H-13 tool was fabricated using Turning Machine following the design and dimension below.

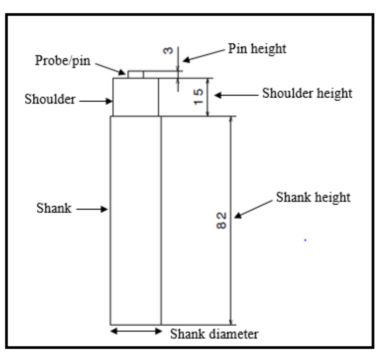


FIGURE 2. Design and dimension of the H-13 tool.

FIGURE 3. After fabricating H-13 tool.

Using the varied machining parameters, the cylindrical tool is rotated and simultaneously, the pin of the tool was stressed into the sample. FSP parameters, to be specific, geometry of tool pin, tool rotational speed and tool transverse speed are recommended for controlling the progression of substantial. Among the particular different parameters, the tool pin profile has a significant job in the gain of material durability or adaptability in the particular field of microstructure in Mg alloys.

Each of the Mg alloy blocks applied with different spindle speeds but the same transverse speed on it to investigate the varied machining parameters of the effectiveness coating Al6061 on Mg alloy. So then, each block has three samples of FSP. Apart from that, the hardness was evaluated using Brinell Hardness Tester to evaluate five readings of hardness on the Mg alloy block and the Al6061 before the FSP as well as the average hardness for both materials were calculated respectively. After FSP process finished, the hardness of Mg alloy merged with Al6061 was tested followed by the microstructure testing on the stirred zone of each samples. Microstructure evaluation was tested by using the 3D Measuring Laser Microscope.

a) b) c)

FIGURE 4. Three samples on each block, a) SS: (920/1165/1439) rpm, TS: 25mm/min, b) SS: (1439/920/1165) rpm, TS: 34mm/min, c) SS: (920/1165/1439) rpm, TS: 46mm/min.

RESULTS AND DISCUSSIONS

Micro Hardness Test

The hardness interpretation managed to achieve the target of this observation. The equipment utilized in this test is Brinell Hardness Tester. The scale that was used in measuring the hardness of these materials is HRB of Brinell Hardness. According to the instruction in a book for load usage value of every material, the load used for testing the material was 588 kN loads. The experiment uses a ball indenter with a diameter of 1.5875 mm. Before running FSP, the average of the hardness was measured. This step was done to ease the comparison section between the results before and after the FSP process. Five readings for each type of material are tabulated in the table below.

TABLE 1. Micro hardness testing HRB study.

HRB	HRB_1	HRB_2	HRB_3	HRB_4	HRB_5	HRB_{avg}
Mg alloy	68.40	69.00	69.20	69.10	70.70	69.28
Al6061	28.60	24.30	24.50	25.00	25.50	25.58

From the Table 1 above, it can be concluded that the average reading of the hardness test showed the value of Mg alloy is higher than Al6061. The Mg alloy gives an average reading of 69.28 which is the maximum significant lower value, and the Al6061 has the least hardness with average reading of 25.58. These readings regulate one of the relations that was found in the investigation for HRB, that Mg alloy is more diligent than Al6061.

After running FSP with coating Al6061 on Mg alloy for each of the blocks, hardness test was done for each of the stirred zone which having the same transverse speed (mm/min) but different in spindle speed (rpm). The surface that merged both materials together undergo facing process so that the ball indenter can touch on the stirred zone of the FSP. Figure 5 below shows the testing on the stirred zone hardness.

FIGURE 5. Hardness test on the stir zone of the FSP.

Doing the same step as before FSP, five readings of hardness test were taken as well as the average of the hardness was calculated. The bar graph in Figure 6 gives better understanding about the average hardness test readings on the stirred zone taken after FSP process.

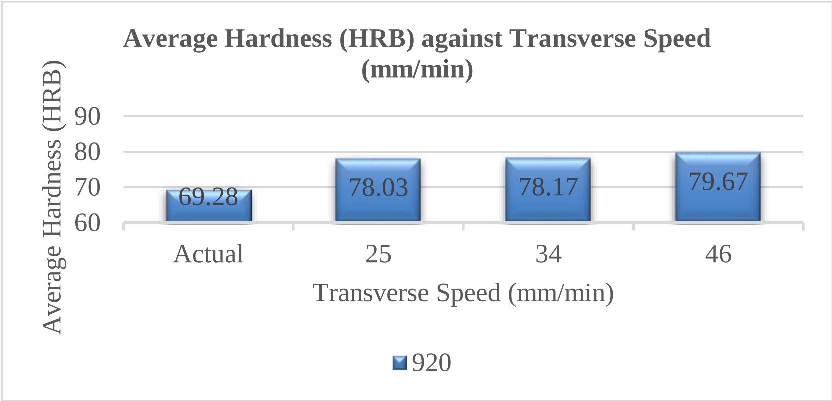


FIGURE 6. Graph of hardness test for spindle speed 920 rpm.

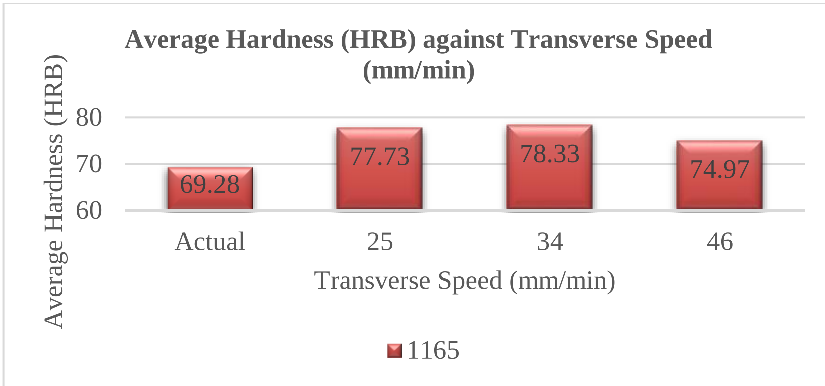


FIGURE 7. Graph of hardness test for spindle speed 1165 rpm.

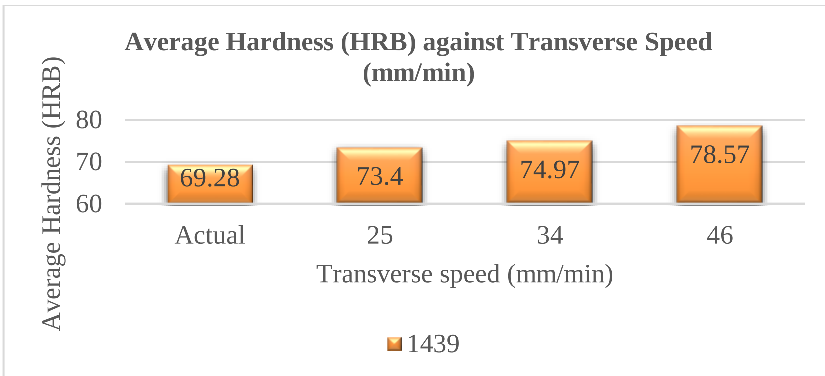


FIGURE 8. Graph of hardness test for spindle speed 1439 rpm.

Before FSP, the hardness test reading on Mg alloy is lesser than after the FSP process. From the graphs, the actual value is below 70 HRB. But after the FSP process, the hardness results for every spindle speed and transverse speed is between the range of 70 to 80 HRB.

Micro Structure Test

The Mg alloy block with coating Al6061 need to be tested under the microscope to analyze the fine-grain refinement after the FSP process was completed. This is important to determine whether the coating performance is better or not. The standard etchant which is Glycol was used to display the microstructure grain refinement. The composition for the etching process is 1 mL of Nitric acid (HNO3), 24 mL of distilled water, and 75 mL of Ethylene Glycol [15]. For that reason, microstructure interpretation was done to accomplish the objective of the study by focusing on the stirred zone of the FSP. Figure 9 below shows the result of microstructure before and after coating with Al6061 using 200 µm scale.

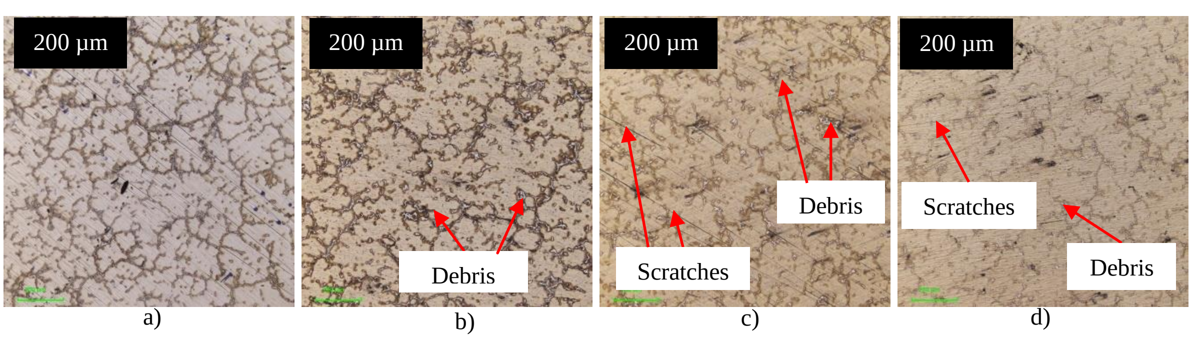
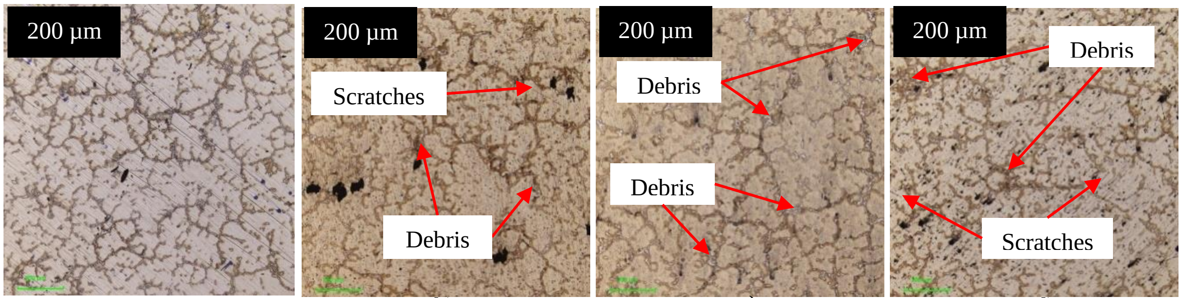


FIGURE 9. Grain structure of Mg alloy, a) Without coating Al6061, b) Coating Al6061 (SS: 920 rpm TS: 25 mm/min), c) Coating Al6061 (SS: 1165 rpm TS: 25 mm/min), d) Coating Al6061 (SS: 1439 rpm TS: 25 mm/min).



a) b) c) d)

FIGURE 10. Grain structure of Mg alloy, a) Without coating Al6061, b) Coating Al6061 (SS: 920 rpm TS: 34 mm/min), c) Coating Al6061 (SS: 1165 rpm TS: 34 mm/min), d) Coating Al6061 (SS: 1439 rpm TS: 34 mm/min).

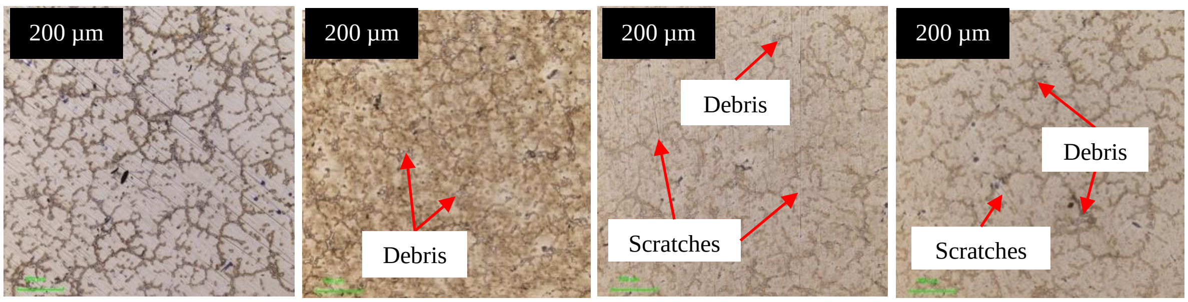


FIGURE 11. Grain structure of Mg alloy, a) Without coating Al6061, b) Coating Al6061 (SS: 920 rpm TS: 46 mm/min), c) Coating Al6061 (SS: 1165 rpm TS: 46 mm/min), d) Coating Al6061 (SS: 1439 rpm TS: 46 mm/min).

From the results obtained, it can be concluded that the Al6061 play roles as a good corrosive protector, high in durability also high in ductility as the grain-refinement for every sample of the FSP process have higher number of existing-slip systems in the hexagonal closed-packed structure. Aluminium alloy that has been merged with the Mg alloy at the stirred zone of the FSP showed that the material at the mixed zone experienced utmost plastic deformation and dynamic recrystallization which prompts refinement of the microstructure, along these lines improving quality and flexibility, increment preservation from erosion and weariness, upgrade formability and improving different properties. To simply conclude, the presence of Al6061 coating on the Mg alloy makes better performance.

CONCLUSIONS

The hardness and microstructure testing were presented as a simple study of measurement on the effect of using varied machining parameters during friction stir processing on the effectiveness of coating Al6061 on Mg alloy. The parameters study had been successfully completed as there was a coating Al6061 that merged together with the Mg alloy block during the FSP process. Moreover, the second objective of this study again achieved when the effectiveness of the coating Al6061 on Mg alloy block proved through a higher hardness reading average from the original Mg alloy without coating. Lastly, the fine-grain structure after the FSP process also had been analyzed where the debris of Al6061 and many fine grain structure of coating Al6061 performed on Mg alloy.

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REFERENCES

1. Y. N. Zhang, X. Cao, S. Larose and P. Wanjara, Can. Metall. Q. 51(3), 250–261 (2012).
2. S. P. Chainarong, Muangjunburee and S. Suthummanon, "Friction Stir Processing of SSM356 Aluminium Alloy" (Procedia Engineering, 2014), pp. 732-740.
3. B. R. Sunil, G. P. K. Reddy, H. Patle and R. Dumpala, J. Magnes. Alloy 4(1), 52–61 (2016).
4. K. Sun, Q. Y. Shi, Y. J. Sun and G. Q. Chen, Mater. Sci. Eng., A 547, 32–37 (2012).
5. T. Rajmohan, K. Gokul Prasad, S. Jeyavignesh, K. Kamesh, S. Karthick and S. Duraimurugan, “Studies on friction stir processing parameters on microstructure and micro hardness of Silicon carbide (SiC) particulate reinforced Magnesium (Mg) surface composites” (IOP Conference Series Materials Science and Engineering, 2018), pp. 0–8.
6. G. Vedabouriswaran and S. Aravindan, J. Magnes. Alloy 6(2), 145–163 (2018).
7. R. S. Mishra and S. Jain, Int. J. Res. Eng. Innov. 1(6), 229–243 (2017).
8. M. S. Węglowski, Arch. Civ. Mech. Eng. 18(1), 114–129 (2018).
9. M. Balakrishnan et al., J. Alloys Compd. 785, 531-541 (2019).
10. H. Zhang, Y. Liu, J. Fan, H. J. Roven, W. Cheng, B. Xu and H. Dong, J. Alloys Compd. 615, 687–692 (2014).
11. N. Singh, J. Singh, B. Singh and N. Singh, “Wear behavior of B4C reinforced AZ91 matrix composite fabricated by FSP” (Materials Today: Proceedings, 2018), pp. 19976–19984.
12. Y. N. Wang et al., Scr. Mater. 55(7), 637-640 (2006).
13. J. Iwaszko, K. Kuda, K. Fila and M. Strzelecka, Arch. Metall. Mater. 61(3), 1209–1214 (2016).
14. G. Venkateswarlu, M. J. Davidson and P. Sammaiah, Journal of Manufacturing and Industrial Engineering 13(1-2), 1-5 (2014).
15. G. V. Voort, "Metallography of Magnesium and its Alloys" (Buehler, 2015).