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Effects of Rotational Speed/Traverse Speed Ratio on AA2024 Alloy Microstructure and Macrostructure in Friction Stir Processing

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Abstract **–** In this study, the effects of rotational speed/traverse speed on microhardness, macrostructure and microstructure of AA2024 material subjected to friction stir processing were examined. The experimental approach involves drilling the samples, filling them with SiC particles, and changing FSP process parameters such as rotational speed and traverse speed in a controlled manner. The processed samples were then subjected to macrostructural and microstructural examinations, as well as Vickers microhardness tests. The highest microhardness value was observed as 120 HV for 33.33 rotational speed/traverse speed ratio. The macrostructural analysis and microhardness analysis showed that the ratio does not have effect on the stir zone widths. Microstructural analysis demonstrated variations in the size and distribution of SiC particles, indicating potential influences of the FSP process and the rotational speed/traverse speed ratio on the microstructural characteristics of the processed material. It showed that as the W/V ratio increases the homogeneity of the particle distribution decreases. These findings highlight the importance of considering the W/V ratio in FSP and the need for further research to fully understand its potential effects on the microstructural and macrostructural properties of processed materials. This study provides valuable information on the friction stir processing of AA2024 alloy, which has important applications in materials engineering and manufacturing industries.

Keywords – Friction Stir Processing, AA2024, SiC particles, Microstructure, Macrostructure, Microhardness

I. Introduction

Friction Stir Processing (FSP), firstly introduced by Mishra et al. in 1999, is a method based on Friction Stir Welding introduced by The Welding Institute (TWI) in 1991, that targets to enhance the properties of surface by stirring added particles to the base material [1-5]. The Friction Stir Processing (FSP) process is carried out using a rotating tool which was plunged into the workpiece. Pressure is applied to the surface of the material and heat is generated due to friction in-between, causing a change in the microstructure of the material [6].

The FSP method, widely occupied in industries like defense, aircraft, and automotive, enables to obtain superior mechanical properties by increasing grain density through plastic deformation [7,8]. The properties of the structure obtained with FSP depend on tool geometry, number of passes, plunge depth, tool advance, and rotation speeds [1,5] .

Moustafa et al. [9] examined the surface mechanical properties of FSPed AA2024 material and demonstrated an improvement of 25% in ultimate tensile strength and 46% in microhardness as a result of the FSP process.

SiC, with its high hardness, wear resistance, and low density, has become a preferred compound in FSP among researchers due to these properties [10-19].

In this study, it was aimed to enhance the mechanical properties of AA2024 alloy by incorporating SiC particles through the friction stir processing. The primary objective was to investigate the influence of rotational speed/traverse speed ratio on the microhardness, macrostructure and microstructure of the resulting composite material.

In contrast to the previous studies mentioned above, this work investigates the effects of the rotational speed (W)/traverse speed (V) ratio on the microhardness, microstructure, and macrostructure of the material.

II. Materials and Method

AA2024 alloy, which is commonly used in the aviation and automotive industries due to its high strength and lightweight properties, was used in this study. The 45 µm average size of SiC powder was selected to improve the mechanical properties of the material. Samples with a thickness of 5 mm were drilled with a 2 mm diameter and 2.5 mm depth, whereas the distance between holes was measured as 2 mm. Then, mechanical deburring was done around holes, followed by filling with SiC particles as shown in Fig.1, and FSP process was carried out using the parameters in Table 1, as shown in Fig.2.

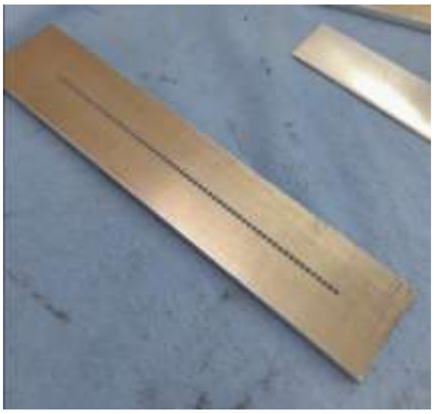

Fig. 1 Samples Filled With Particles

Fig. 2 (a) FSP Setup; (b) Processed Samples

Table 1. FSP Parameters

Sample No.	Rotational Speed (rpm)	Traverse Speed (mm/min)	Number of Passes	W/V Ratio
1	1000	30	2	33.33
2	1250	30	2	41.66
3	1000	20	2	50

The processed samples were cut and polished. Tucker's reagent and Keller's reagent were used to reveal macro and microstructures respectively. Vickers microhardness test was performed to observe the effect of the FSP on AA2024 material.

III. RESULTS AND DISCUSSION

A. *Microhardness*

It can be seen from Table 2 that maximum microhardness value was obtained as 120 HV for Sample 1 with 33.33 W/V ratio. It can be observed in Fig.3 that different ratios do not have an effect on the stir zone widths for all samples. According to Fig.3 and Table 2, it is seen that the increase in the hardness profile of the material varies between 43% and 62% compared to the pre-FSP state. Tests also revealed that hardness increase is evident up to 22 mm was observed on samples.

Table 2. Microhardness Results

		Hardness (HV)	
Sample No.	W/V Ratio	Before FSP	After FSP
1	33.33	75.3	120
2	41.66	70.7	115
3	50	79	113

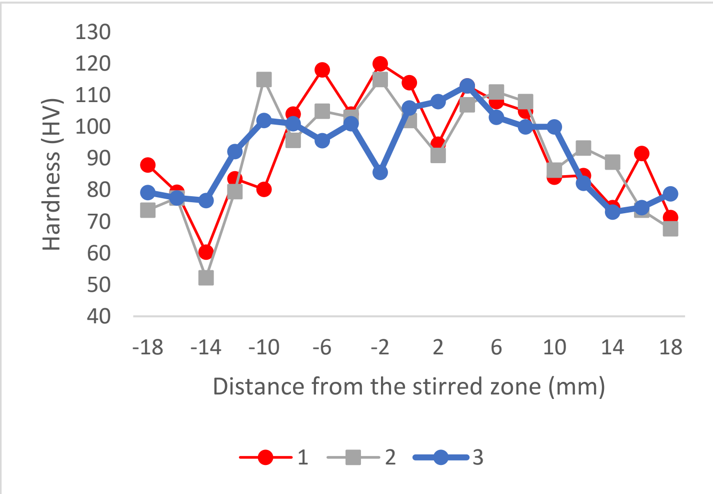

Fig. 3 Microhardness Results

B. *Macrostructure*

Macrostructure analysis revealed consistent results across all samples, indicating that the W/V ratios did not have a significant impact on the stir zone widths, as seen in Fig.4. The maximum stir zone width measured for all samples is between 21.6 mm and 22.2 mm.

In summary, the macrostructural analysis confirms that the friction stir processing technique consistently produces uniform macrostructural features, regardless of the specific W/V ratio used for processing the AA2024 alloy with SiC particle reinforcement.

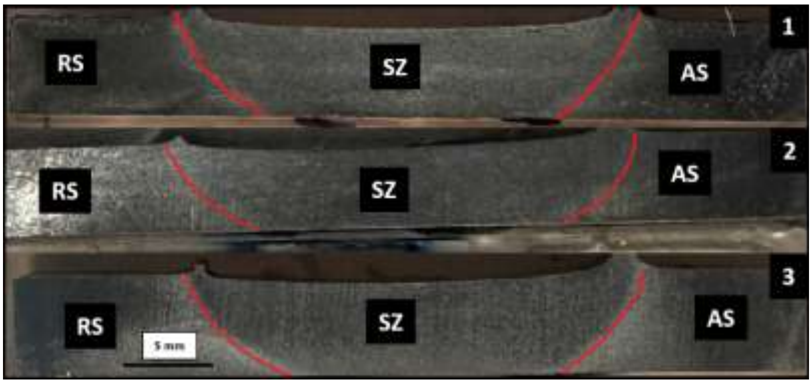

Fig. 4 Macrostructure of the Processed samples

C. *Microstructure*

In the microstructure examination, it was observed that the particle sizes varied between 8-15 µm in the areas close to the surface, and between 15-30 µm as the depth increased. This change in particle size distribution indicates the effect of the FSP process on microstructural changes within the material.

Furthermore, Fig. 5 shows that samples 1 and 2 exhibited a similar and relatively homogeneous particle distribution, while sample 3 was observed to show a less uniform distribution.

Microstructural analysis provides valuable information about the distribution, size variation and distribution patterns of SiC particles within the processed AA2024 alloy.

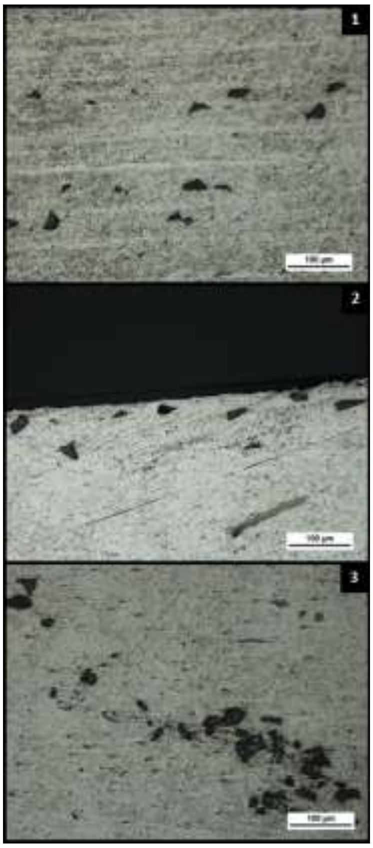

Fig. 5 Microstructure of the Processed Samples

IV. CONCLUSION

The study has provided valuable insights into the mechanical, macrostructural and microstructural changes by FSP, with following results:

- The aim of the study was to investigate how rotational speed (W)/transition speed (V) ratio affects the microhardness, macrostructure and microstructure of the friction stir processed AA2024 alloy.
- Macrostructural analysis showed that the W/V ratio affects stir zone widths. Still, this effect is low due to the effect of rapid cooling due to the high heat conduction coefficient of aluminium alloys.
- Microstructural analysis revealed differences in the size and distribution of SiC particles. This suggested that the FSP process and W/V ratio could affect the microstructural properties of the material. As the ratio increases, the homogeneous distribution of SiC particles decreases.
- The findings highlight the importance of considering the W/V ratio in FSP and its potential effects on the microstructural and macrostructural properties of the processed material.

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