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Friction Stirs Processing - State of The Art Process to Fabricate Metal Matrix Composites

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Abstract

Friction stir processing(FSP) is the solid state method to fabricate the surface metal matrix composites(MMC). This process has been derived from the concept of Friction stir welding. As this process is performed in solid state, many defects related to phase transformation can be avoided. As this process is done below the melting point temperature of metal or alloy, it is easier to control the process. Machine variables (tool rotational speed, tool traverse speed, tool tilt angle etc.), tool design variables (diameter, profile and height of probe and shoulder of the FSP tool), and material properties are the main process variables to perform FSP in order to fabricate Metal matrix composite. In addition to these variables number of passes, tool traverse patterns, reinforcement particles' content and its' types also can be considered as process variables. Tribological properties' comparison can be done between alloy and MMC fabricated by FSP for different combinations of process parameters. Microstructural study also can be carried out in order to see the effects of above process parameters. In this paper the above aspects are summarized and performance assessment done by various researchers has been covered.

Keywords: *Friction stir processing, Surface Metal matrix composites, Tribological study, Microstructure study.*

1. Introduction

A metal matrix composite (MMC) is composite material with at least two constituent parts, one being a metal necessarily, the other material may be a different metal or another material, such as a ceramic or organic compound [1]. In surface composites the second material is spatially distributed in the near surface regions (Singh et. al.). It has been shown in Figure 1 [2-6]. When at least three materials are present, it is called a hybrid composite. Friction stir processing (FSP) is a novel approach to fabricate metal matrix composites in surface region of the matrix material. For FSP a specialized tool is designed Shown in Figure 2. There are two methods, Groove method and Hole method, for addition of reinforcement particles into the matrix material. It has been shown in Figure 3.

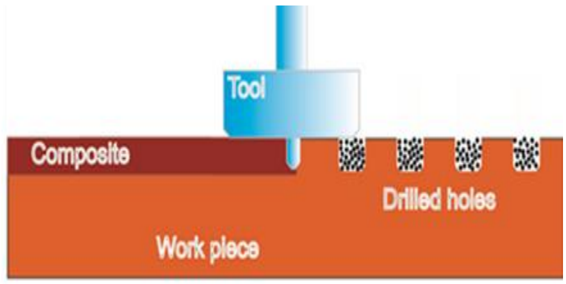

Figure 1 Surface Composite (Sharma V. et. al.)

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Figure 2 Tool Used During FSP (Rathee et. al.)

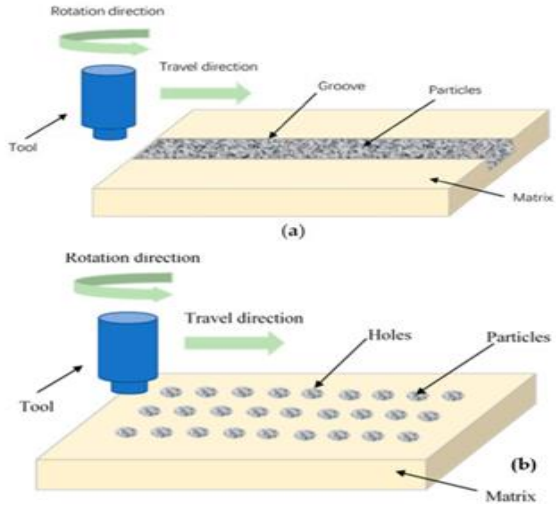

Figure 3 Adding Particle Methods of Fabricating the Surface Composites: (A) Groove; (B) Holes (Li. Et. Al.)

In Figure 4, various process parameters for FSP has been shown [7, 8]. These process parameters are mainly machine variables, tool design variables and material properties of the reinforcement particles.

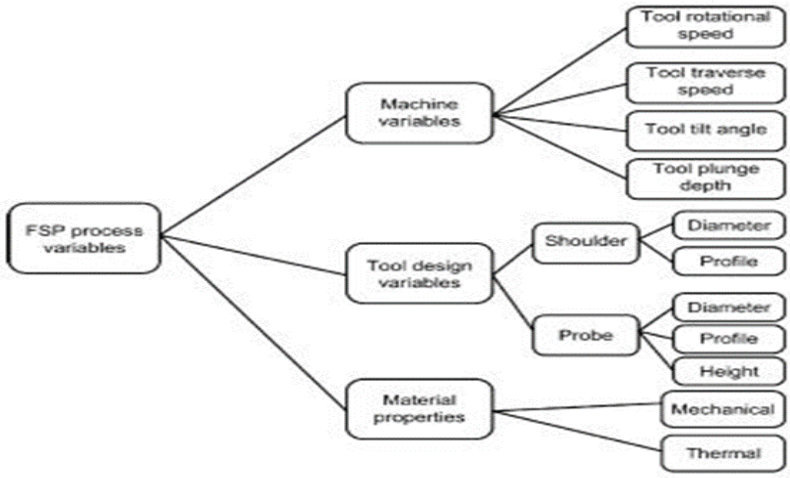

Figure 4 FSP Process Variables (Sharma V. et. Al.)

In addition to these variables number of passes, tool traverse patterns, reinforcement particles' content and its' types also can be considered as process variables (Węglowski et. al.) (Bauri et. al.) [9-15].

2. Literature Review

Many of the researchers have worked to check the effects of process parameters for different types of study. Table 1 shows the data of effect of different methods of adding reinforcement and types of reinforcement on wear resistance, mechanical properties, microstructure, no. of passes [16-24]. Table 2 shows the data of effects on wear resistance, mechanical properties, microstructure, no. of passes for different process parameters [25-34]. Table 3 shows the data for effects on axial force, traverse force, side force, and torque required for different process parameters [35-37].

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Table 1 Effects on Wear Resistance, Mechanical Properties, Microstructure, No. Of Passes by Different Methods of Adding Reinforcement

Author	Matrix material	Reinforcement material	Method of Adding Reinforcement	Key remarks
Alidokht et. al., 2011	A356	SiC + MoS2	Groove	Wear resistance improved, particle distribution is uniform.
Hosseini et. al., 2015	AA5083	CeO2 + CNTs	Groove	The tensile strength increased with increasing volume fraction of carbon nanotubes [CNTs].
Srinivasu et. al.,2015	A356	B4C + MoS2	Holes	Hardness and wear resistance increased.
Parumandla et al., 2018	AA 6061-T6	Al2O3 + SiC	Groove	Wear resistance of surface nanocomposites was increased with increasing volume percentage of reinforcement.
Akbari et. al., 2017	A356	Sio2+ Al2O3	Groove	Hardness improvement, Uniform distribution of particles
C.M. Maxwell Rejil et. al., 2012	AA6360	Tic + B4C	Groove	The microstructure and sliding wear behavior of the fabricated SCLs were evaluated.
D. K. Sharma et. al., 2019	AA6061	B_4C+MoS_2	Holes	Having 25% of MoS2 resulted in the best hardness and wear resistance Properties, Multiple processing passes resulted in the dissolution of precipitates resulting in reduced hardness.
D. K. Sharma et. al., 2021	AA6061	B_4C+MoS_2	Holes and grooves	Hole method revealed ~13 % better wear resistance compared to the groove method for friction stir processed hybrid surface composite, attributing to an improved homogeneity of particle distribution shown by zigzag hole pattern.
Eskandaria et. al., 2015	AA8026	Al_2O_3 + TiB_2	Groove	Improved distributions of nanoparticles were obtained after each FSP pass and progress in mechanical properties was observed.

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Table 2 Effects on Wear Resistance, Mechanical Properties, Microstructure, No. Of Passes for Different Process Parameters

Author	Matrix material	Reinforcement material	Parameters of Study	Key remarks
Aruri et. al.,2013	AA 6061-T6	SiC + Gr, SiC+Al_2O_3	Tool Rotational Speed (increasing)	Increased Micro hardness, Lower wear rate. Graphite acts as a solid lubricant, Decreased Tensile Properties
Kumar et. al.,2015	AA 6061	Mg + Fly Ash, Mg + Gr	Effect of reinforcement	Adding fly ash increased the tensile strength, Adding Graphite lead the tensile strength and hardness to decrease
Dinaharan et. al., 2014	AA 6082	SiC, Al_2O_3, TiC, B_4C, WC	Tool rotation speed, tool traverse speed, Groove width and type of ceramic	High hardness and low wear were noted at less tool rotational speed, high tool traverse speed, highest groove width and with TiC particles
Dinaharan et. al. 2014	AA 6061	Al3Ti, Al3Zr	Intermetallic reinforcement	Friction Stir processed specimen with intermetallic reinforcement resulted in improved wear resistance
S. A. Alidokht et. al., 2011	A356	SiC+MoS2	Reinforcement	Sound surface composites with uniformly distributed reinforcement were Developed, Adding MoS2 further enhances the wear as compared to SiC
Devaraju et. al. 2013	AA-6061-T6	SiC+Al2O3	Rotational speed and reinforcements	The optimum value for rotational speed and proportion of reinforcement were found using Taguchi Method, Significant improvement in wear was observed at the optimum conditions.
Devaraju, et. al. 2013	AA 6061-T6	SiC+ Gr, SiC+Al2O3	Reinforcements	Uniformly distributed reinforcement help achieve better properties, Addition of graphite as opposed to alumina reduced hardness but increased the wear resistance
Soleymani et. al. 2013	AA 5083	SiC+MoS2	Reinforcement and FSP	Sound hybrid composites were formed, The hybrid composites had better surface properties as compared to composites with single reinforcement, Delamination along with little abrasion was seen in hybrid composites
Sudhakar et.al. 2015	AA 7075	B4C+MoS2	Reinforcement and FSP	Hybrid surface composites showed better properties of wear resistance, Ballistic resistance of the surface composites was higher as compared to the base metal.
Miranda et. al. 2013	AA 5083 H111	SiC, Al2O3	FSP tool	For SiC reinforcement, tool wear was present, although sound composites were Produced, An approach of using a consumable tool with prefilled reinforcement has shown to enhance particle retention. This also avoids defects and produces sound Composites, The consumable tool approach is suitable for various combinations of reinforcements

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Table 3 Effects on Axial Force, Traverse Force, Side Force, and Torque Required for Different Process Parameters

Author	Material for FSP	Key remarks
K.S. Arora, et. al. ,2010	AA2219-T87	Establishment of Relationship between parameters and Fx force, increase in rotational speed, shoulder diameter and pin diameter caused increase in the Fx force, however, increase in the travelling speed caused decrease in this force.
Trimble et. al. ,2012	AA2024-T3	Increasing the travelling speed causes the increase in the torque, traverse and vertical forces.
Farazila Yusof et. al. ,2015	AA 5052	The tool rotational speed increased, the downward force decreased and the longitudinal force increased when operating under the same condition. The tool rotational speed had no significant effect on travel speed.

Conclusion

As per the results obtained by various researchers it is clearly notable that FSP is a novel approach for fabrication of surface MMC. It affirms the improvement in wear resistance of the matrix material. As it is a solid state process it also ensures the absence of the phase transformational defects. The handling of the material also becomes easier in this process with respect to other processes such as thermal spraying, casting, cladding, powder metallurgy etc. It also ensures the chemical stability, dimensional stability at high temperature, improvement in the corrosion resistance, Improvement in the mechanical properties, Reduction of the porosity of castings, good strength to weight ratio, FSP is a green technology – no welding fumes and dusts. By looking at these much of advantageous of FSP we can say that it is a superior process among other alternatives of it in order to fabricate Surface metal matrix composite.

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