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EFFECT OF PROCESS PARAMETERS OF FRICTION STIR PROCESSING ON MECHANICAL PROPERTIES – A REVIEW

[a]Abhishesh Mishra, [b]Vinay Kumar Jaiswal, [c]Rajnish Singh,

[a] M. Tech. Scholar, Department of Mechanical Engineering, IT SRMU Barabanki, U.P., India,
[b]Assistant Professor, Department of Mechanical Engineering, IT SRMU Barabanki, U.P., India
[c]Assistant Professor, Department of Mechanical Engineering, IT SRMU Barabanki, U.P., India

ABSTRACT

Friction stir processing (FSP) was originally developed for aluminium alloys based on the basic principles of friction stir welding (FSW), a solid-state joining process, is an emerging metal working technique that can provide localized modification and control of microstructures in near-surface layers of processed metallic components. The FSP causes intense plastic deformation, material mixing, and thermal exposure, resulting in significant microstructural refinement, densification, and homogeneity of the processed zone. The FSP technique has been successfully used for producing the fine-grained structure and surface composite, modifying the microstructure of materials so FSPed areas are superior in strength and also have superior formability compared to parent material. This processing also helps to convert a heterogeneous microstructure to a more homogeneous and refined microstructure.

In this review paper survey the literature on FSP, the current state of the understanding and development of FSP effect on mechanical properties is addressed. Differences between effect of FSP parameters on different conditions and their result are addressed.

Keywords – FSP; Al alloys; Al matrix composite; mechanical properties; microstructure.

I.INTRODUCTION

Friction stir processing (FSP) technique which based on the friction stir welding, developed for the microstructural modification of material to change its specific properties [1]. In FSP, a non consumable rotating tool with profiled pin and larger diameter shoulder is forcibly inserted into single piece of workpiece, and the traversing the tool across the surface [1,2]

When friction stir processing technique used, it can eliminate casting defect at localised area and refined microstructures, so that improving strength and ductility, enhances fatigue and corrosion resistance, formability and improve other properties such as hardness [2]. FSP is carried out by localised heating, generated by friction between tool and workpiece. Material is stirred from front to the back of the pin and produced processed zone [3].

FSP technique has been used [1]

1) To produce surface composite on aluminium substrate.
2) Homogenization of powder metallurgy aluminium alloy.
3) Microstructural modification of metal matrix composite [1], powder metal objects [3].
4) Property enhancement in cast aluminium alloys.
5) FSP has been applied to Al, Cu, Fe, Mg and Ni based alloys with resulting properties improvement [2].
6) FSP removes various casting defects and homogenise it [3].

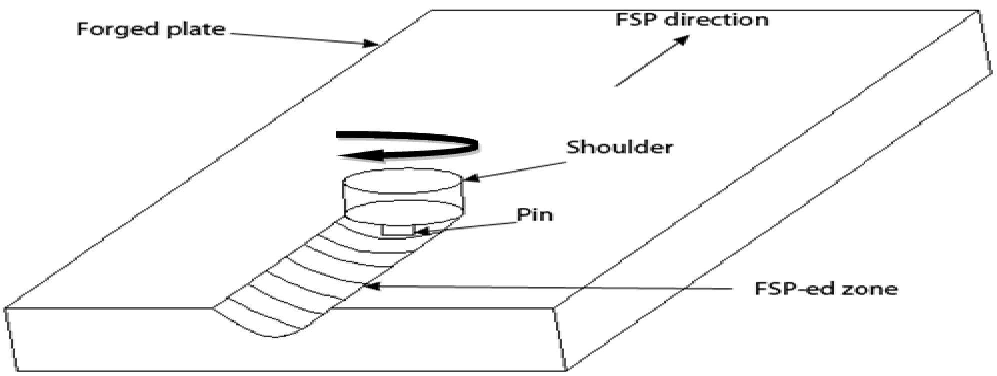

Fig.1 Principle of FSP [3]

II. PARAMETERS

Parameters which affect FSP performance as it is based on FSW are

1) Tool rotation rate (rpm)
2) Tool traverse or progressive speed (mm/min)
3) Axial or down force (kN)
4) Tool geometry

The effect of each of the parameter is as shown in below Table 1

Table.1 FSP parameters and its effects [4]

Sr. No.	Parameter	Effect of parameter
1.	Tool rotation rate (rpm)	Frictional heat, stirring, oxide layer breaking and mixing of material
2.	Tool traverse or progressive speed (mm/min)	Heat control and appearance
3.	Axial or down force (kN)	Frictional heat and maintaining contact conditions
4.	Tool geometry	The appearance of processed zone

For this research we studies how improvement in mechanical properties and microstructure of different aluminium alloys by FSP.

III. MICROSTRUCTURE

Result came from FSP on SSM (semi solid metal) 356 Al alloy at rotational speed : 1320, 1480 and 1750 rpm and traverse speed : 80, 120 and 160 mm/min found that by increasing traverse speed grain size decreases due to silicon particle distribution more uniform at high traverse speed. Increasing rotational speed result in stirred to high temperature causes larger grain size which causes reduction of mechanical properties of the material. On the advancing side which is in same direction as workpiece movement resulted in pull friction and found that high rotation speed has larger grains than low rotation speed where as the retreating side which is in opposite direction to the workpiece movement resulted in compressed friction from tool rotation and found that high rotation speed has smaller grains than low rotation speed. Void occurs at very low temperature [6].

Result from FSP on cast hypereutectic Al – 17% Si alloy at rotational speed 664 rpm and traverse speed 26, 40 and 60 mm/min found that Si particle size reduces and improves its distribution compare to base metal and so reduces the crack sensitive zone [7].

Result came from FSP on Aluminium Alloy Matrix/ TiB_2/ Al_2O_3 Hybrid Surface Nanocomposite and found that Al_2O_3 and TiB_2 particles uniformly distributed in Aluminium matrix and reinforcement particle interface which is due to increase in the rheology (deformation and flow of matter) of plastic material in stir zone. By FSP high heat input recrystallized aluminium matrix and cause grain refinement [8].

Result came from Al7075/ B4C surface composite by FSP at rotational speed 545 rpm and traverse speed 50, 78 and 120 mm/min found that best powder distribution achieved at 50 mm/min traverse speed. Higher agglomeration at advancing side (AS) occurs as material not transferred from advancing side to retreating side (RS) due to plunge or axial force and rotational movement is insufficient to counteract the flow stresses produced by material. Defects are generated at insufficient stirring by very low rotational speed [9].

IV. RESULTS AND DISCUSSION

1) Hardness

By increasing rotational speed and decreasing traverse speed in FSP hardness of base metal alloy or composite reduces due to rheology increases of plastic materials [6, 7, 8]. By increasing no of passes, microstructure of base metal refined and grain size decreases of aluminium matrix so that hardness of surface composite increased [8].

It is observed from studies of Al 7075-T651 base metal FSPed that as increasing traverse speed, hardness is reduces due to reduction in stirring time, leads to lower particle distribution and reduces in grain refinement [9]. According to Orchard’s law, the wear rate of metallic materials is inversely proportional to the hardness of the material. The drop in microhardness of the AMCs weakens the ability to resist the removal of metal in course of sliding wear.[11] The microhardness of the AA6082 AMCs (Fig. 7b) decreases as tool rotational speed is increased from 800 to 1600 rpm which was measured to be 158 HV at 800 rpm and 124 HV at 1600 rpm as in Fig.7.[11]

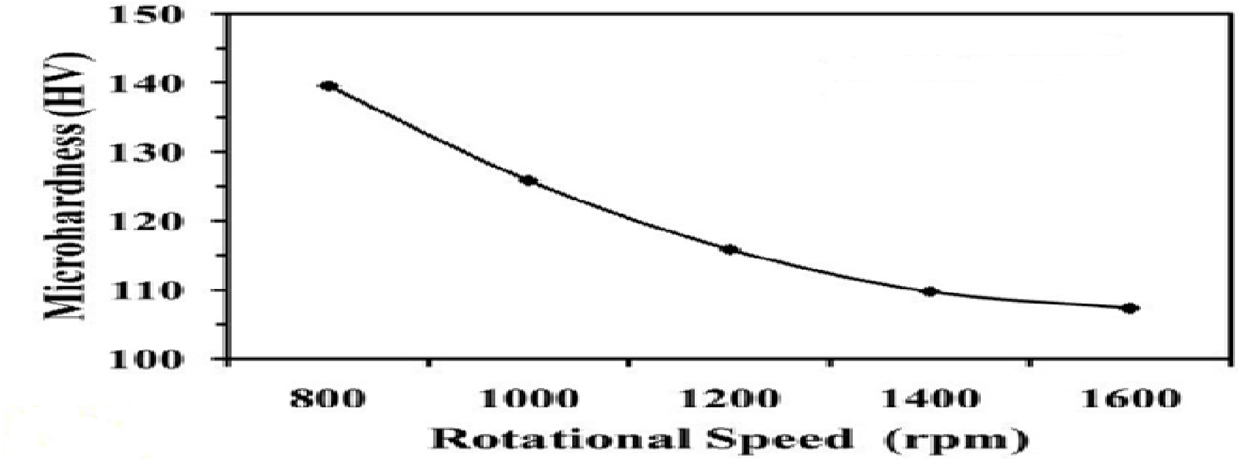

Fig.2. Effect of tool rotational speed on microhardness [11]

The microhardness of the AA6082 AMCs (Fig.8) increases as traverse speed is raised from 20 mm/min (120 HV) to 100 mm/min (157 HV) due to the decrease in interparticle distance.[11]

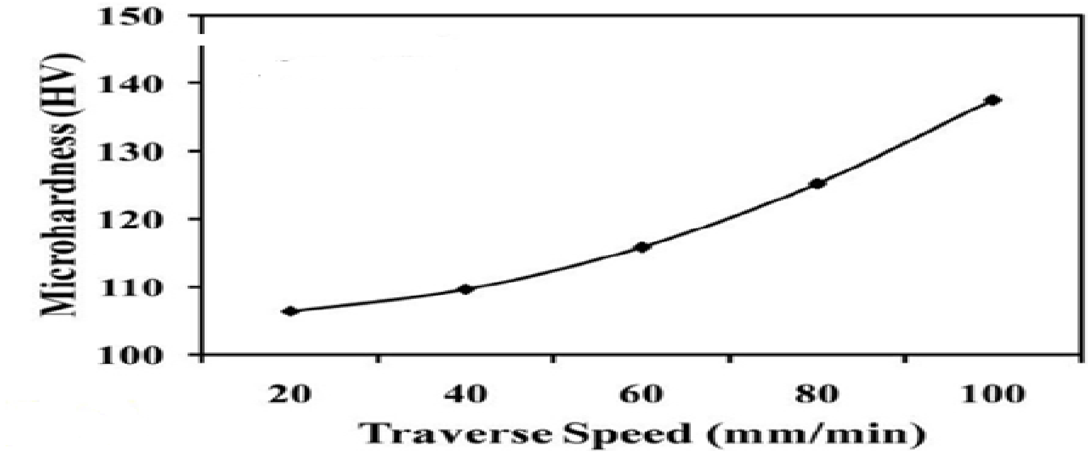

Fig.3. Effect of tool traverse speed on microhardness [11]

FSP causes microstructural enhancement which resulted in elimination of porosity, the more uniform distribution of the finer Si particles and the grain refinement of the cast alloy as the number of passes increase. The dominant strengthening mechanism which led to the increase in hardness is the grain boundary strengthening.[13] Increasing the number of FSP passes caused a higher microhardness of composite materials through a more uniform dispersion of reinforcement particles, as well as grain refinement of the Al matrix.[14]

2) Tensile strength

Tensile strength is affected by heat generated during FSP. When heat generated during stirred is too much the tensile strength becomes less than base metal as at 1320, 1480, 1750 rpm rotational speed and 80 mm/min traverse speed in SSM 356 workpiece [6]. By increasing rotational speed at same traverse speed tensile strength decreases [6, 8]. By increasing traverse speed at same rotational speed tensile strength increases in SSM 356 Al alloy and aluminium matrix composite [6, 8], whereas tensile strength decreases in Al – 17% Si alloy. By increasing number of passes at same rotational and traverse speed, tensile strength increases.

3) Yield Strength

Yield strength increases after FSP but decreases with increase traversing speed.[7] More number of FSP passes showed a superior mechanical performance due to more uniform dispersion of $ZrSiO_4$ particles. Yield strength increases as the microstructure was refined during the FSP.[14]

4) Wear resistance

According to Orchard’s law, the wear rate of metallic materials is inversely proportional to the hardness of the material. The drop in microhardness of the AMCs weakens the ability to resist the removal of metal in course of sliding wear The increase in tool rotational speed increased the mean interparticle distance and drop in hardness of the AMCs so wear resistance decreases as fig.9. The wear rate of the AA6082 AMCs (Fig. 10c) decreases as traverse speed is raised from 20 mm/min ($421 \times 10^{-5} mm^3/m$) to 100 mm/min ($362 \times 10^{-5}$ mm^3/m) as fig.10.[11]

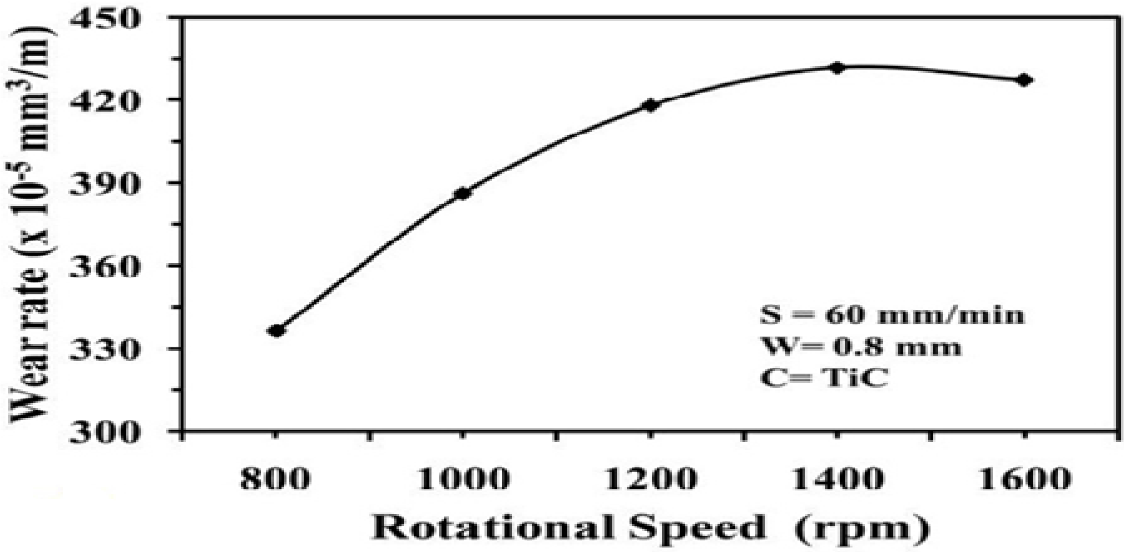

Fig.4. Effect of tool rotational speed on wear rate of AA6082 AMCS [11]

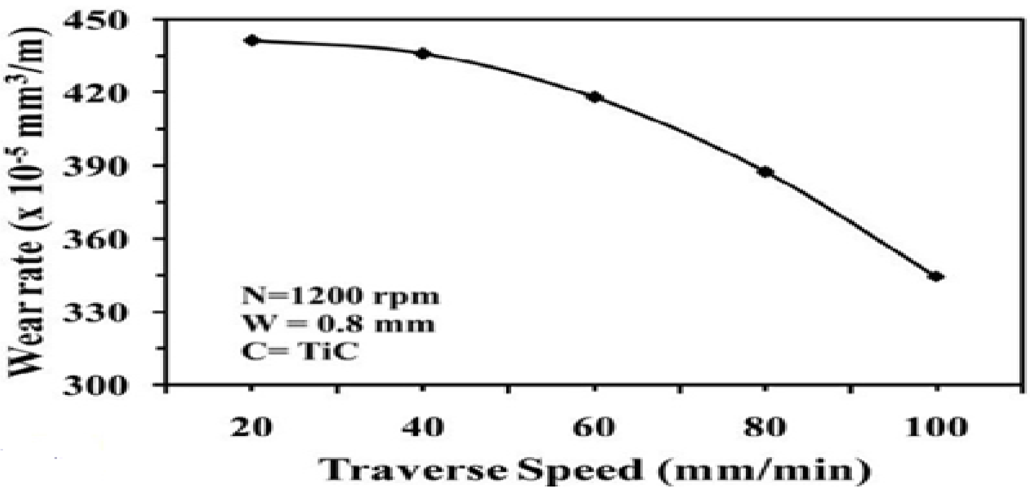

Fig.5. Effect of tool traverse speed on wear rate of AA6082 AMCS [11]

The wear resistance in abrasive wear condition is maximum for the materials subjected to both 1 pass and 2 pass FSP. Enhanced ductility in FSP 3 Pass material made it more prone to μ-cutting thereby decreasing its wear resistance.[12]

5) Corrosion resistance

Increasing the number of FSP passes provides a uniform dispersion of the reinforcement ($ZrSiO_4$) particles, decreased the surface pores and homogenizes and refines the microstructure. This promotes the formation of a uniform, strongly adhering passive layer and thereby increases the corrosion resistance.[14]

V. CONCLUSION

FSP leads to significant microstructural refinement, homogenization and elimination of casting porosity. The 3 pass FSP on as-cast material showed better ductility whereas the solution treated material possesses better strength.

By increasing traverse speed better distribution of Si particle occur, reduction in the crack sensitive zone, powder distribution, stirring time, and area of stir zone with it grain size, surface roughness, yield strength, rheology (deformation & flow of matter) of the plastic material and wear rate decreases, whereas microhardness increases. By the reduction of the average inter particle distance particle clusters occur.

By increasing rotational speed material stirred to high temperature, Al matrix recrystallized, reinforcement particles better distributed in the Al matrix. Grain size, rheology, stir zone area and mean interparticle distance increases where as hardness, tensile strength decreases. Drop in hardness of the AMCs leads to decrease in wear resistance.

By increasing the no of passes, more uniform distribution of Si particle which eliminates the interface delamination with grain microstructure refined. Grain size of Al matrix particle and aspect ratio reduced, friction coefficient, Si particle size, porosity due to microstructural enhancement decreases whereas increase in hardness by the grain boundary strengthening. Strength, wear resistance, density, corrosion resistance and yield strength increases. Strength obtained by FSP in solution treated material is higher than the as-cast material. Machinability first increases and then decreases due to the refinement and redistribution of the silicon particles. It prevents the material from premature crack initiation with Superior mechanical performance and exhibited a more elongation before fracture.

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