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A Detailed Review on Fabrication and Characterization of Metal Matrix Composites Using Friction Stir Processing

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ABSTRACT-- Composites *manufacturing is an excellent technique in the history of materials. Metal matrix composites (MMCs) have good mechanical properties and excellent microstructures. Friction Stir Process is a modified technique of Friction Stir Welding to produce MMCs. In this Paper, I discussed a large number of research papers and work done by different authors. Mainly in these papers, I discussed Tool materials, Process Parameters and Results. Cu (copper) and Al (Aluminium) matrix is used in many research papers. Aluminium and Silicon reinforcing particles are used. These particles change the property of material. These particles should be properly mixed with matrix for producing good results.*

Keywords: - MMC, FSP, Aluminium and Magnesium alloy, SEM, Copper alloy

1. INTRODUCTION

The demand for weight reduction in car and aircraft fabrication produces the optimization of the design of products employing low weight materials. Therefore, the replacing of conventional materials by lighter metals such as aluminum alloys is highly acceptable. However, aluminum alloys alone are not sufficiently strong for many purposes and their reinforcement is very necessary. Aluminum based metal matrix composites (Al-MMCs) are outstanding candidates for these applications. Such materials are attracted towards the automobile and aerospace industries due to their better properties like wear resistance, high coefficient of friction and strength. We can be done machining on metal matrix composites (MMCs) [1-4].

However dispersion of the reinforcements in a uniform manner in MMCs is a critical and difficult task. It should be noted out that the existing processing techniques for fabrication of surface composites are based on liquid phase processing at high temperatures such as casting and plasma spraying. In these particular cases, it is hard to avoid the interfacial reaction between reinforcement and metal matrix. We have done the processing of composites at temperatures below melting point of substrate to avoid these difficulties. Recently, very much focus has been paid to a new surface modification technique called friction stir processing. FSP (Friction Stir Process) is a technique by which reinforced particles are uniformly distributed in the matrix. FSP is done using the same method as used in the friction stir welding (FSW) process, in which a non-consumable rotating tool with a specially designed pin and shoulder is plunged into the interface between two plates to be joined and traversed along the line of the joint [5-8]. Localize heat is produced by the friction between the rotating tool and the work piece leading the temperature of the material to rise. The material undergoes intense plastic deformation resulting in significant grain refinement though FSP has been basically termed as a grain refinement technique; it is a very attractive process for also fabricating the composites [9-13]. In this method we have to cut one or more grooves along the FSP direction which are filled by reinforcing particles. The FSP (friction stir process) is conducted along the groove to produce metal matrix composite. By doing this, Process characteristics like hardness, wear resistance, corrosion resistance and tensile strength improved [14-20]. Barmouz et al. [21] produced copper reinforced metal matrix composite (MMC) layers using SiC particles by friction stir processing (FSP) in order to improve surface mechanical properties. FSP tool was made of hot working steel with shoulder diameter, square pin diameter and length of 20, 5 and 2mm. Process parameters are tool rotational speed (710-1120rpm) and traverse speed (40-200mm/min).A processing tool was tilted by an angle of 2º. Very high values of traverse speeds results in very bad dispersion of SiC particles and reduced the micro hardness values of MMCs layers. Wear properties and coefficient of friction were improved upon addition of SiC powder. I. S. Lee et al. [22] used Powder metallurgical route to produce metal matrix composite, after that they used FSP. The material used in this work is atomized aluminium powder and silicon powder. A milling machine was adopted to carry out the FSP. The tool for FSP in this study has a shoulder of 16mm diameter and tool pin is standard M1.2 x 6.

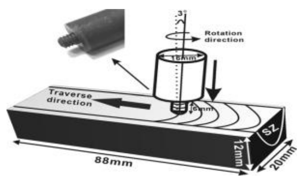

Fig no.-1 (Layout of the friction stir process)

Layout of the friction stir process (FSP) shown in the fig. No.1.A tool rotation speed of 700 rpm was used and traverse speed is 45mm/min. Tool spindle angle is 3º.

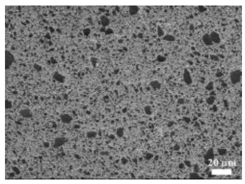

Fig No.-2
(SEM of Al–30Si specimens produced by four FSP passes with tool
Rotating at 700 rpm (etched by 0.5%HF solution).The dark phase is Si particle.)

The FSP specimens have fine SiC particles uniformly dispersed in the Al matrix. The SEM of Al-30Si specimen shown in the figure no. - 2. As compared with Al specimen, these Al-Si composites show enhanced strength and significant work hardening capacity. Young's modulus and Strength increases with increasing in Si content. Y. mazaheri et al. [23] produced A356/Al_2O_3 surface nanocomposites by friction stir processing (FSP). Tool rotation rate, Traverse speed and tilt of spindle were 1600rpm, 200mm/min and 2 degree. The results show that the uniform distribution of Al_2O_3 particles in A356 matrix by FSP process improves the mechanical properties like strength and hardness of specimens. Mehdi Zohoor et al. [24] produced AA5083 aluminium alloy with reinforced layers using copper particles via FSP. The material of tool used in this work was H13 steel with shoulder diameter of 16mm.Tool pin used is standard M6 x 1 with pin height of 3.2mm.Tool Rotational speed were 750 and 1900 rpm. Tool traverse speed was 25mm/min and tilted angle was of 3º. Specimens with micro and nano sized particles present fine grains and higher level of hardness. The composite with nano sized particles exhibited enhanced tensile strength and ductility rather than AA5083 Aluminium alloy. Wei Wang et al. [25] produced bulk SiC_P reinforced aluminium metal matrix composites by friction stir processing. Commercial SiC_P (10μm size) and 5A06Al rolled plate were used in this test. The FSP tool was made of high speed steel and had a columnar shape shoulder (ϕ18mm) and a screwed pin (ϕ6mm). The rotational speed of tool was 1180 rpm and travel speed was 95mm/min. along the center line. Tool tilt forward angle of 2.5º was used. Excellent bonding between SiC_P and base metal can be obtained by this process. The micro hardness of MMCs increases. M. Azizieh et al. [26] showed the effect of Tool rotational speed and pin profile on microstructure and hardness of AZ31/Al_2O_3 (Aluminium oxide) Metal matrix composite composites manufactured by friction stir processing (FSP). Three types of tool profiles are used :- i) A tool with a probe without threads, ii) A tool with a probe with threads.iii) A tool with a probe with threads and three flutes. The tool made of H13, and heat treated to have 53 HRC hardness. They consisted of a shoulder with diameter 18mm, a probe with diameter of 6mm and a length of 5.7mm.The threaded probe had 1mm pitch and the fluted probe have three flutes with depth of 1.5mm. For each pin profile a constant traverse speed of 45mm/min was taken. Rotational speed of Tool was 800, 1000 and 1200rpm. Tool tilt angle of 2º was considered. FSP passes are 2 and 4. By giving increment in the rotational speed, as a result of more heat input, grain size of base alloy increased and causes a better distribution. The average grain size of matrix of the composite was in the range of 1-5μm and the micro hardness of them was 85-92Hv. Ranjit Bauri et al. [27] studied the effect of friction stir processing (FSP) parameters on microstructure and properties of Al-TiC in-situ composite. FSP tool is made of M2 tool steel and essentially consists of a shoulder of diameter of 12mm and a tool pin of diameter of 4mm and length of 3.5mm.Tool rotational speed of 1000rpm and traverse speed of 60mm/min was used. A downward force of 5KN was used. A single pass of FSP was enough to break the particle segregation from the grain boundaries and also improve the distribution of reinforcing particles. Two FSP passes produced complete homogenization. After each FSP pass, grain size was refined. Hardness and Tensile Properties improved after FSP. Jinwen Qian et al. [28] fabricated ultra grained institute synthesized Al_3Ni particle reinforced composites by friction stir processing by incorporating Ni powder into the stirred zone of 1100-H14 aluminium alloy. The tool was made of W18Cr4V high speed steel (H.S.S) with a columnar shaped shoulder (ϕ25mm) and a screw thread tapered pin (root dia: 9.6mm, tip: ϕ5mm, length: 6mm). The rotational speed of tool was 1180 rpm, and the travel speed 60mm/min. along the center line of the groove. The analysis showed that the Al-Ni in-situ synthesizing product was Al_3Ni.When the specimen was stirred two passes, the formed Al_3Ni was tiny to be detected.Al_3Ni subsequently became apparent when stirring 4 and 6 passes and the fine Al_3Ni particles were dispersed homogeneously in the composites, which caused significant increase in the micro hardness and tensile Strength. M. Sharifitabar et al. [29] made 5052 Al/Al_2O_3 ceramics particle reinforced composite by friction stir processing process. The Hardened H-13 tool steel pin was 5mm in diameter and its length was about 3.7mm with a shoulder diameter of 13.6mm.FSP carried out with different tool rotation speed to tool travel speed ratio(w/v) ranging from 8 to 100 rev/mm and tilting angle of pin (ϕ) ranging from 2.5º to 5º. Result indicated that grain size of stir zone decreased with increasing in the FSP pass and the composite fabricated by four passes produced uniform distribution of Al_2O_3 Aluminium oxide reinforcement particles. Tensile test results indicated that Tensile and yield strengths were higher. All FSP samples had higher elongation than base metal. S. Soleymani et al. [30] fabricated Al5083 based surface hybrid metal matrix composite (SHMMC) reinforced with a mixture of SiC and MoS_2 particles by friction stir processing (FSP). A tool made of H-13 steel with a shoulder of 20mm diameter. For performing the FSP process, Tool pin used of 6mm diagonal length, 2.8mm height and 3º tilt angle. Single pass friction stir process (FSP) with tool rotation speed of 1250rpm and tool traverse speed of 50mm/min was used. These conditions produced the best results in terms of homogeneity of the particles inside the nugget zone for producing the SHMMC of Al alloy used in this study.

Microstructure of composite showed a uniform distribution of reinforcing particles and an excellent bonding between surface processed layer and base material occurs. The tribological studies showed that SHMMC has the highest wear resistance in comparison to other samples. Qiang Liu et al. [31] fabricated muti-walled carbon nanotubes reinforced aluminium matrix composites by friction stir processing. Holes with the same depth but different diameters, i.e. six holes with a depth of 3.5mm and a diameter of 0mm, 2mm, 4mm, 6mm, 8mm and 10mm respectively were drilled by a drilling machine on the surface of aluminium plates. After filling the holes with various quantities of MWCNTs, these plates were processed by FSP. The FSP procedure was schematically shown in fig No.3. During FSP, the forward velocity of rotating pin was kept as a constant of about 30mm/min, and a rotational speed of 950rpm was used. Five passes on same position were conducted on each plate to achieve the uniform distribution of MWCNTs in the matrix material. It was indicated that MWCNTs were well dispersed in the Aluminium matrix throughout the FSP. With the increase of MWCNT particles, tensile strength and hardness of MWCNTs/Al composites gradually increases. K. Sun et al. [32] examined microstructure and mechanical property of nano-SiC reinforced high strength Mg bulk composites produced by friction stir processing. The traverse speed of the FSP tool was 20mm/min and tool rotation speed was 1500rpm. Tool Tilt angle during FSP was 2.5º, 5 FSP passes were applied in the same position in this study in order to make the reinforced particles distributed uniformly in nugget zone.

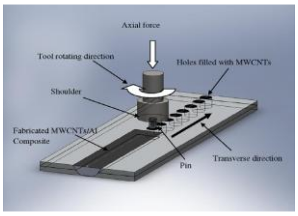

Fig.No.-3(Schematic diagram of FSP)

Plates without groove were also friction stir processed for five passes in the same position as comparison group. Fine and uniform nugget zone were found both in comparison group and composite. SiC particles were found both inside the grain as well as at the grain boundary. The effect of nanoparticle on strength increases was significant. A.Shafiei-Zarghani et al. [33] had done wear test of Al/Al_2O_3 nanocomposite produced using friction stir processing (FSP). Hardened H-13 tool steel was used that consisted of a shoulder with a diameter of 16mm and a pin with a diameter and a length of 5 and 4mm respectively. The Tool tilt angle was fixed at 3º.The tool rotation speed was at 1250 rpm, and the tool traverse speed of 135mm/min. Substrates were subjected to various no. of FSP passes from one to four. Scanning electron microscopy (SEM) studies showed that increase in the no. of FSP passes causes a more uniform distribution of particles. The mean micro hardness value of surface nano-composite layer was found to be improved by almost three times as compared to that of the as-received Aluminium matrix. Wear resistance was improved by FSP. Mohsen Barmouz et al. [34] fabricated Cu/SiC composites using multi-pass friction stir processing and checked microstructure, porosity, mechanical properties. The optimum rotational and traverse speeds were 900rpm and 40mm/min. Processing tool was tilted by an angle of 2º. FSP tool was made of hot-working steel with the shoulder diameter, square pin diameter and length of 20, 5 and 2mm respectively. Field emission scanning electron microscopy and optical microscopy images indicate that multi-pass FSP enhances the separation and distribution of SiC particles and also reduces the grain size. The results showed that we got higher micro hardness values and tensile strength by multi pass FSP. M. Puviyarasan et al. [35] has done optimization of friction stir process parameters in fabricating $AA6061/SiC_p$ composites. Taguchi experimental design and optimization approach was applied to determine the combination of most influential process parameters that yield better tensile strength. A high speed steel (HSS) tool, with a flat shoulder of 18mm diameter and a threaded cylindrical pin of 6mm diameter,5.9mm long was used for processing. All FSP studies were carried out for single-pass and the process parameters are tool rotation speed (1200-1800 RPM), traverse speed (36-72mm/min), tool tilt angle (1-3̊).The predicted optimum value of Tensile Strength is 189MPa. A.N. Albakri et al. [36] have done a numerical and experimental investigation for Thermo-mechanical and metallurgical aspects in friction stir processing of AZ31 Mg alloy. The Tool is made up of H13 steel and heat-treated to a hardness of 52-55Rc.Tool had a shoulder diameter of 13mm and tool pin is 6mm in diameter and 3mm in length. Two set of process parameters were used. In first set the following parameters were applied: 1000rpm, 1400rpm and 2000rpm at a constant translational speed of $9mms^{-1}$, while in the second set $3mms^{-1}$, $6mms^{-1}$ and $9mms^{-1}$ translational speed at a constant rotational speed of 1000rpm were applied. The numerical results showed that rotational speed as compared to translational speed had a more dominant effect on temperature field and strain rate. Experiments revealed that a defect free and coarse microstructure was obtained at rotational speeds higher than 1000rpm. The increase in translational speed resulted in finer grain sizes without formation of voids or defects. R. S. Mishra et al. [37] successfully fabricated Al-SiC surface composites with different volume fractions of particles. The aluminium plates with SiC particle layer were subjected to FSP (friction stir Process). A tool with a pin height of 1.0 mm was used. Tool rotating rate of 300 rpm was taken. The tool spindle angle of 2.58 was used. The SiC particles were uniformly distributed in the matrix. The reinforcing particles in surface composites have excellent bonding with the aluminium alloy substrate. Surface composite reinforced with SiC had micro hardness (173 HV), almost double of the 5083Al alloy substrate (85 HV). Surface composites have very fine structure. J. Gandra et al. [38] produced aluminium based MMC (Metal Matrix Composites) reinforced by SiC ceramic particles. The tool consisted of a 7 mm diameter threaded cylindrical probe and a 18 mm concave shoulder in H13 tool steel quenched and tempered and hardened by ion nit riding up to a hardness of 1250 HV. The tool was rotating at 1000 rpm with a travelling speed of 250 mm/min and a 2º tilt angle. A tool penetration of 2 mm was used. A vertical tool force of about 9.8 KN was used. It was seen that it was more effective when the groove was placed under the probe. If the groove was placed outside the probe, but within the shoulder influence area, insufficient dispersion of particles was observed. K. J. Hodder et al. [39] fabricated aluminum-alumina metal matrix composite via cold gas dynamic spraying at low pressure followed by friction stir processing. The parameters of FSP are tool rotation speed (894-1723 rpm); traverse speed is 88mm/min and 3̊ tool tilt angle. The tool was plunged into the sample such that the entire surface was in contact with the coating. The hardness of the MMC increased to a maximum of 137HV. FSP (Friction Stir Process) was effective in dispersing these Al_2O_3 particles and decreasing their mean free path. Al_2O_3 particle size refinement during FSP improved the hardness of the MMC Coatings. S. Tutunchilar et al. [40] used DEFORM-3D software to develop a 3-D lagrangian incremental finite element method (FEM) simulation of friction stir processing. The shoulder and pin diameter, and pin height were 18, 6, and 4 mm, respectively. The tool rotational and the traverse speeds were also 900 rpm and 50 mm/min, respectively. The tilt angle was fixed at 3º. The results reveal that the main part of the material flow occurs near the top surface and at the advancing side (AS). Material at the top surface was in stretched condition to the advancing side producing a non symmetrical shape of the stir zone (SZ). The comparison proves that the stir zone shape, defect types and temperature rise which were predicted by simulation, are matching with the corresponding experimental results. L. Suvarna Raju et al. [41] fabricated Cu-Al_2O_3 surface composites by friction stir processing. Process parameters are tool rotation speed (900RPM), Traverse Speed (40mm/min.). Tool material is H-13 Tool Steel. Tool shoulder diameter is 24mm. Square pin diameter is 8 mm and length of pin is 2mm. Result shows that Al_2O_3 particles are uniformly distributed in stir zone. Microhardness increases due to presence of hard Al_2O_3 particles. Tensile properties increased with increase in percentage of Al_2O_3 particles. H. Eskandari et al [42] fabricated Aluminium alloy Matrix/TiB_2/Al_2O_3 Hybrid surface nano composite by Friction stir processing. Tool is made of H13 Tool steel. Diameter and length of pin is 5mm. Shoulder diameter is 18mm. Threatened pin with a pitch size of 0.5mm.Groove depth and width is of 4.2mm and 1.2mm. Process parameters are Tool Rotation speed (800-1600), Traverse speed (40-80), number of passes 2-4 and tool tilt angle is 3̊. Results shows that improved distribution of nano particles were obtained after each FSP Pass and progress in mechanical properties was obtained. S. Ramesh babu et al. [43] finds the effect of tool shoulder diameter during friction stir processing of AZ31B alloy sheets of various thicknesses. They used two Friction stir tools made of High Carbon Steel. Pin diameter and length is of 6mm and 5.8mm. Shoulder diameter is of 18mm and 24mm resp. Process parameters are Tool rotation speed (1000-1800 RPM), Tool Traverse speed (22-105) mm/min. Result proves that increase in shoulder diameter between 18mm and 24mm, a defect free zone was observed for variation in process parameters in 6mm thick plate. A. Thangarasu et al. [44] shows the effect of traverse speed on microstructure and mechanical properties of AA 6082 - TiC Metal Matrix composite fabricated by friction stir processing (FSP). Tool is made up of high carbon high chromium and hardened to 62HRC. Tool Shoulder is 22mm diameter and Pin is having Threaded profile M6X1 mm and length of 5.5mm. Process parameters are 10KN force, Tool Rotational speed is 1200 RPM and Tool Traverse speed is 40 to 80 in steps of 20mm/min. Results shows that Traverse speed influenced the area of surface composite, dispersion of TiC, grain size of matrix, micro hardness. R. Sathiskumar et al. [45] shows the effect of Traverse speed on microstructure and micro hardness of Cu/B_4C Metal matrix composite produced by friction stir processing (FSP). Tool is made up of Double Tempered Hot working steel. Tool Shoulder diameter is 20 mm. Pin diameters and length is 5 and 3 mm. Process parameters are Tool rotation speed (1000 rpm), axial force (10KN), Traverse speed is 20 to 60 in step of 20mm/min. Result shows that lower traverse speed exhibited homogeneous distribution of B_4C particles while higher traverse speed caused poor distribution of B_4C particles. The micro hardness of surface composite increased when traverse speed was increased. Vivek V. Patel et al. [46] find the influence of pin profile on tool plunge stage in friction stir processing of Al-Zn-Mg-Cu Alloy. They use the tool profiles (Conical, Square, Pentagon and Hexagon). Tool material is of Tool steel of M2 grade. Tool shoulder is of 20mm diameter. Threaded conical pin (6mm at root and 3mm at tip), Polygonal pins cross-section were inscribed in a circle of 6mm diameter. All pin profile was 6mm in length and plunged 6.5 mm into the work piece. Process parameters are tool rotation speed (765RPM), Traverse Speed (31.5mm/min), Tool Tilt angle (2̊). Result shows that the temperature due to plastic deformation at pin was less than the temperature caused by friction on work piece. Compared to other pin profiles, Pentagon pin generated more temperature during plunging. Sandeep Rathee et al.[47] finds groove dimensions effect on microstructure and mechanical properties of AA6063/SiC (silicon carbide) metal matrix composites(MMC) produced by friction stir processing(FSP). Process parameters are Tool Rotation speed (1400 RPM), Traverse speed (56mm/min) and Tool Tilt angle (2̊). Tool material is H-13 Tool Steel. Shoulder Dia is 20mm. Threaded pin M (6x1) diameter and length is 6mm and 2.5mm. Base metal plate were machined with- no groove, 1,2,3 and 4mm groove width in centre of each plate along the length direction. Result shows that a ratio of width to pin diameter (w/d) of 0.5 was found optimum for developing high volume percentage of 40% of SiC reinforced surface composites.

Table No.-1
SUMMARY OF THE INVESTIGATION ON METAL MATRIX COMPOSITES

S. No.	INVESTIGA-TOR NAME	MATERIAL INVESTIGATED	PARAMETERS	CHARACTERI-STICS STUDIES	RESULTS
1.	Barmouz et al.[21]	Pure copper plate, 5µm SiC particles	Tool rotational speed (710-1120rpm) and traverse speed (40-200mm/min)	Microstructure, Microhardness, Wear and Friction Coefficient and Tensile Strength	➢ Higher traverse speeds resulted in poor dispersion of SiC particles and consequently reduced the micro hardness values of MMC layers ➢ Upon addition of SiC particles, Wear properties and average friction coefficient were improved. Strength and elongation were reduced.
2.	I. S. Lee et al.[22]	Atomized aluminium powder and silicon powder.	A tool rotation speed of 700 rpm was used and traverse	Microstructure, yield strength, young's modulus	➢ FSP specimens have fine Si particles uniformly dispersed in the Al matrix. Stir Zone was free of porosity. ➢ Strength and young's modulus

			speed is 45mm/min. Tool spindle angle is 3°,four FSP passes		increases with increasing Si content
3.	Y. mazaheri et al.[23]	A356-T6 10mm x 50mm x 250mm bars	Tool rotation rate, Traverse speed and tilt of spindle were 1600rpm, 200mm/min and 2°.	Microstructure, Hardness, Elastic Modulus	➢ Uniform distribution of Al_2O_3 particles in A356 matrix by FSP process can improve the mechanical properties of specimens. ➢ The hardness and elastic modulus of the as – received A356, the sample treated by FSP without Al_2O_3 particles , surface micro- and nanocomposite specimens were about 75Hv and 74GPa,69Hv and 73 GPa,90Hv and 81GPa,110Hv and 86 Gpa, respectively.
4.	Mehdi Zohoor et al.[24]	Al 5083 sheet with 130mm length,60mm width, Cu particles	Tool Rotational speed was 750 and 1900 rpm. Tool traverse speed was 25mm/min and tilted angle was of 3°.	microstructure, particles distribution pattern and micro hardness	➢ Specimens with micro and nano sized particles present fine grains and higher level of hardness. The composite with nano sized particles exhibited enhanced tensile strength and ductility rather than AA5083 Aluminium alloy.
5.	Wei Wang et al.[25]	Commercial SiC_P(10μm size) and 5A06Al rolled plate	The rotational speed of tool was 1180 rpm and travel speed was 95mm/min. along the center line. Tool tilt forward angle of 2.5° was used.	Distribution of SiC particles and micro hardness	➢ Excellent bonding between SiC_P and base metal can be obtained by this process. The distribution of well-dispersed SiC_P got a range of 5mm x 2mm on the cross-section of joints. ➢ The micro hardness of MMCs increases 10% than base metal at the depth of 1mm under the upper surface.
6.	M. Azizieh et al[26]	AZ31 billets and three kinds of Al_2O_3 particles with mean diameter of 35nm,350nm and 1000nm respectively	A constant travel speed of 45mm/min was adopted. Tool rotation speed of 800, 1000 and 1200rpm was applied. Tool tilt angle of 2° was considered. FSP passes	Nano particle distribution , matrix microstructure and micro hardness	➢ By increasing the rotational speed, as a result of greater heat input, grain size of base alloy increased and simultaneously more shattering effect of rotation causes a better nanoparticle distribution. The average grain size of matrix of the composite was in the range of 1-5μm and the micro hardness of them was 85-92Hv.

			are 2 and 4		
7.	Ranjit Bauri et al.[27]	A mixture of K_2TiF_6 and graphite powder in aluminium melt	Tool rotational speed of 1000rpm and traverse speed of 60mm/min was used. A downward force of 5KN was used.	Microstructure, phase analysis, hardness and tensile strength	➢ A single pass of FSP was enough to break the particle segregation from the grain boundaries and improve the distribution. ➢ Two passes of FSP resulted in complete homogenization and elimination of defects. ➢ Hardness and Tensile Properties improved after FSP.
8.	Jinwen Qian et al.[28]	Commercially available pure aluminium alloy 1100-H14 rolled plate with 8mm thickness was used as substrate. Ni powder have an average diameter 25-38μm,purity 99.9 wt%	The rotational speed of tool was 1180 rpm, and the travel speed 60mm/min.	The microstructure, distribution of the intermetallic particles, the compositions of the composites, Micro-hardness and Ultimate tensile strength(UTS)	➢ When the specimen was stirred two passes, the formed Al_3Ni was tiny to be detected.Al_3Ni subsequently became apparent when stirring 4 and 6 passes and the fine Al_3Ni particles were dispersed homogeneously in the composites, which caused significant increase in the micro hardness and UTS of the composites
9.	M. Sharifitabar et al.[29]	Commercial aluminium alloy 5052-H32 rolled plate, nano-size Al_2O_3 powder	Different tool rotation speed to tool travel speed ratio (w/v) ranging from 8 to 100 rev/mm and tilting angle of pin (ϕ) ranging from 2.5° to 5° were used.	Distribution of Al_2O_3 particles, Tensile strength, yield strength and Elongation	➢ Grain size of stir zone (SZ) decreased with increasing of FSP pass and the composite fabricated by four passes had submicron mean grain size. ➢ Increase in the FSP pass caused uniform distribution of Al_2O_3 particles in the matrix. ➢ Tensile strength and elongation of the base material improved to 118% and 165% in the composite fabricated by four passes respectively.
10.	S. Soleymani et al.[30]	Commercially Al5083 rolled plates, a mixture of SiC and MoS_2 powders at weight ratio of 2 to 1 were used as the reinforcement	Tool rotation speed of 1250rpm and travel speed of 50mm/min was used. A tilt angle of 3° was used.	Micro structural observation, Hardness, wear Resistance	➢ Microstructure analyses of hybrid composite showed a uniform distribution of reinforcing particles inside the processes zone and a good bonding between surface processed layer and base material. ➢ The tribological studies showed that SHMMC has the highest wear resistance in comparison to other samples. ➢ The addition of SiC particles into surface layer ofAl5083 alloy via FSP has dramatically increased the

					hardness of base metal.
11.	Qiang Liu et al.[31]	Plates of A1016 commercial aluminium alloy, muti-walled carbon nanotubes reinforced particles	Forward Velocity of rotating pin was kept as a constant of about 30mm/min, and a rotational speed of 950rpm was used. Five FSP passes on same position	Dispersion of MWCNTs in Al matrix, Micro-hardness, Tensile Strength	➢ MWCNTs were well dispersed in the Aluminium matrix throughout the FSP. ➢ With the increase of MWCNT content, tensile strength and micro hardness of MWCNTs/Al composites gradually increased, but on the contrary, the elongation decreased. ➢ The maximum ultimate tensile strength reached up to 190.2MPa when 6 vol. % MWCNTs were added, and this value was two times more of that of aluminium matrix. ➢ The composites become more and more brittle with the increase of the MWCNT content.
12.	K. Sun et al.[32]	Commercial SiC particles and as-casted AZ63 alloy plate were used as reinforced particles and base metal	The travelling speed of the FSP tool was 20mm/min and rotation speed was 1500rpm.The Tilt angle during FSP was 2.5º,5 FSP passes were applied in the same position	Microstructure, Distribution of SiC particles, Hardness, Ultimate Tensile Strength,	➢ Fine and uniform nugget zone were found both in comparison group and composite. SiC particles were found inside the grain as well as at the grain boundary. ➢ The average vicker hardness of base metal, comparison group and composite were 80Hv, 85Hv and 109Hv respectively. ➢ The ultimate tensile strength (UTS) of the composite reached 312MPa compared with 160MPa of the as-casted Mg alloy, 263MPa of the comparison group. ➢ The effect of nanoparticle on strength increases was significant.
13.	A.Shafiei-Zarghani et al.[33]	An A6082 commercial Al-Mg-Si alloy extruded bar was used, Nano–sized Al_2O_3 powder used as reinforcement particles	The shoulder tilt angle was fixed at 3º.The tool rotation rate was adjusted at 1250 rpm, and the rotating tool was traversed at a speed of 135mm/min. along the axis of the work piece. Substrates	Distribution of alumina particles and matrix grain size of SCLs(Surface Composite Layers), micro hardness, wear resistance	➢ Scanning electron microscopy studies showed that increase in the no. of FSP passes causes a more uniform dispersion of alumina particles and thus decreases particles clustering. ➢ The mean micro hardness value of surface nano-composite layer was found to be improved by almost three times as compared to that of the as-received Al alloy substrate. ➢ Wear Resistance also improved.

			were subjected to various no. of FSP passes from one to four.		
14.	Mohsen Barmouz et al.[34]	A pure copper plate (130mm x 75mm x 6mm) was used, 5µm SiC particles were used.	The rotational and traverse speeds were 900rpm and 40mm/min. Tool was tilted by an angle of 2º.	Microstructure, Microhardness, Friction coefficient and X-ray analysis, Tensile strength.	➢ Multi-pass FSP enhances the separation and distribution of SiC particles and also reduces the grain size. ➢ Higher micro hardness values and tensile properties were achieved by higher number of FSP passes. ➢ Average coefficients of friction of composites were reduced compared to the pure copper. ➢ Addition of SiC improves electrical resistivity of pure copper.
15.	M. Puviyarasan et al.[35]	Material used is AA6061-T6 alloy, 100mm in length, 70mm in width and 10mm in thickness. SiC particles(3µm particle size)	Tool rotation speed, Traverse speed and Tilt angle were set at 1800rpm, 58mm/min. and 2º, respectively.	Tensile Strength	➢ The predicted optimum value of Tensile Strength of FSP fabricated AA6061/SiC_p composite is 189MPa.

SUMMARY AND DISCUSSION

FSP is a successful method to produce Metal Matrix Composites (MMC). The FSP parameters selection is a great challenge to produce sound composite zone means uniform distribution of reinforcement particles in the matrix. Very fine particles used for reinforcement improve the grain structure and also improve the overall properties of the material in the form of increased young's modulus, micro hardness and Tensile strength. The large amount of plastic strain produced by FSP can shear the metal powders and break the oxide film surrounding reinforcement particles, which causes contact between the matrix and the reinforcement particles and promotes the reaction. The tendency of particle agglomeration can be significantly reduced by appropriate selection of an FSP tool shoulder diameter, which is responsible for the generation of frictional and shear forces.

The application of the FSP (Friction Stir Processing) technique in generating Metal Matrix composites made it in the field of Composite manufacturing. Further research in this area and better understanding of the process parameters can give area for the success of this FSP technology.

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