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Friction stir processing (FSP) of aluminum alloys for improving mechanical and tribological properties

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Abstract

A new microstructural modifications technique was developed by the Welding Institute (TWI) of United Kingdom in 1991 is known as Friction stir processing (FSP). The FSP is a newer technique used for refining and homogenizing the grain structure of metal sheet. Friction stir processing is a great potential in the field of super plasticity and metal matrix composites. Many investigators observed that the FSP greatly enhances super plasticity in many Al alloys. It is a is a solid-state processing technique based on friction stir welding technique in which a specially designed rotating cylindrical tool that comprises of a probe and shoulder. The probe of the tool is inserted into the sheet material while rotating and the shoulder moves over the surface of the sheet, and then traverses in the desired direction. The contact between the rotating probe and the sheet material generate heat due to friction which softens the material and the mechanical stirring caused by the probe, the material within the processed zone undergoes intense plastic deformation yielding a dynamically-recrystallized fine grain microstructure.
This paper mainly deals with friction stir processing of magnesium alloys with different reinforcement and different input parameters. The study consist of the effect of different reinforcement addition methods that i.e. groove method and drill hole method on tribological and mechanical properties. The result shows that the addition of reinforcements improves the ultimate tensile strength, strain rate and wear resistance.

Keywords: Friction stir processing, Tool rotation speed (TRS), transverse speed (TS)

1. Introduction

Friction stir processing is a novel technique used for improving material properties with the help of a rotation tool by plastic deformation. Friction stir processing is used to make the grain structure homogenous that enhance the properties of material. Friction stir processing is totally based on the friction stir welding technique in which there is a rotating tool consists of a shoulder and a probe. The probe of the tool plunged into the material and produces heat due to friction with the work material. The shoulder produces the additional heat and also capped the material extruded out during the process. Friction stir processing is mostly used for making surface composite, bulk composite and super-plasticity.

2. Literature Review

Today friction stir processing is going to use on all industrial materials for tribological and mechanical properties improvement. Most of the work is going on aluminium alloys because of large application of aluminium alloys in aerospace, marine and automobile industries. The literature consists of the work conducted on various aluminum alloys by friction stir processing. The study consist of various parameters, tool materials, tool dimensions, response parameters and results obtained by various researchers on aluminum alloys by friction stir processing. The literature in the tabular form is given below

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S.N	Year	Author	Title of paper	Work-Piece/ Tool and groove size	Input parameters	Output parameters	Finding
1	2002	Ma.Z., et al	Superplastic deformation behaviour of friction stir processed 7075Al alloy	AA- 7075 with Thickness of 6.5 mm	➢ Tool rotating speed (rpm) - 350,400. ➢ Welding Feeds 203 (mm/min) -	➢ Microstructural characteristics ➢ Superplastic behavior ➢ Topography of deformed specimens ➢ Dynamic grain growth and elongation	➢ Heat treatment for 1 hour at 490 °C showed that the fine grain micro-structures were stable at high temperatures. Superplastic investigations in the temperature range of 420–530 °C and strain rate range of 1×10^{3}–1×10^{1} s-1 demonstrated that a decrease in grain size significantly enhanced superplasticity. ➢ For the 3.8 µm 7075Al alloy, superplastic elongations of 1250% at 480 °C were obtained in the strain rate range of 3×10 3–3×10^{2} s 1, whereas the 7.5 µm 7075Al alloy exhibited a maximum ductility of 1042% at 500 °C and strain rate range 3×10^{3} s 1.
2	2003	Mishra.R. S et al	Friction stir processing: a novel technique for fabrication of surface composite	SiC powder and 5083Al alloy	➢ Tool pin height 1 mm. ➢ Tool rotating rate - 300 rpm ➢ Tool tilt angle 2.5° Tool traverse rate (mm /min - 25.4 & 101.6 ➢ Target depth (mm) - 1.78, 2.03& 2.28	➢ Optical micrograph. ➢ Microhardness (HV) of surface composites and aluminum substrate	➢ By controlling processing parameters, well-distributed particles surface of Al /SiC composite layers of 50 /200 mm with were generated with very good bonding with aluminum substrate. The microhardness (HV) with 27 vol.% of SiC particles of the surface composite was doubled.
3	2004	Sharma.R. S et al	Effect of friction stir processing on fatigue behavior of A356 alloy	A356 plates	➢ Tool rotating speed 900 rpm ➢ Welding Feeds 203 mm/min	➢ Microstructure evolution. ➢ Fatigue properties. ➢ Fractography	➢ The result showed the improvement in fatigue stress threshold stress more than 80% of the FSP sample. This improvement in fatigue properties is recognized to an increased effective crack length and decline in crack growth rate. ➢ FSP modifies the microstructures in regions leading high fatigue loading and improves the overall performance of aluminum castings.

4	2005	Ma.Z.Y.,e t al	Effect of multiple-pass friction stir processing on microstructure and tensile properties of a cast aluminum–silicon alloy	Sand-cast A356 plates composition of 7.20Si–0.36Mg–0.13Fe–0.16Ti–bal Al (in wt.%), Thickness 15 mm	➢ Tool Shoulder diameter 15 mm. ➢ Tool tri-flute pin diameter 4 mm. ➢ Tool tri-flute pin length 2.7 mm. ➢ Tool rotation speed 700 rpm. ➢ Tool traverse speed 203 mm/min	➢ Microstructure of 5-pass FSP A356. ➢ UTS (MPa) ➢ YS (MPa) ➢ El. (%)	➢ Friction stir processing (FSP) of A356 cast is obtained with five-passes with 50% overlap but the Overlapping did not exert a significant effect on the size and distribution of the Si particles. ➢ The effect of T6-heat treatment on the tensile properties were similar across various passes and comparable to those of the single-pass FSP sample.
5	2007	Elangovan .k.,et al	Influences of tool pin profile and axial force on the formation of friction stir processing zone in AA6061 aluminium alloy	AA6061 aluminium alloy, Thickness - 6 (300×150 mm) mm Tool Material - high carbon steel, Square butt joint	➢ Tool shoulder dia 18 mm. ➢ Tool pin dia 6 mm. ➢ Tool threaded pin length 5.5 mm. ➢ Tool rotating speed 1200 rpm ➢ Welding Feeds (mm/sec) 1.25 ➢ Axial force 6, 7.0 and 8.0 KN	➢ Macrostructure ➢ Tensile Properties Effect of tool pin profile Effect of axial force	➢ Five different tool pin profiles were used to fabricate the FSP composites and result showed that square pin profiled tools produce defect-free, good quality FSP region, irrespective to axial force. ➢ An axial force of 7 kN exhibits a defect-free FSP region, irrespective of tool pin profiles. ➢ A smaller grains refinement with uniformly distributed finer strengthening precipitates and higher hardness and superior tensile properties with no defects FSPed Obtained.
6	2009	El-Danaf. E.A.,et al	Friction stir processing: An effective technique to refine grain structure and enhance ductility	AA5083; Thickness - 3 mm Tool Material - H13 tool steel	➢ Tool Shoulder diameter 15 mm. ➢ Tool pin dia 4 mm. ➢ Tool pin length 2.7 mm ➢ Tool rotation speed 430rpm ➢ Tool traverse speed - 140 mm/min	➢ Micro hardness ➢ Microstructure ➢ True stress ➢ True strain response for tensile tests	➢ The ductility of FSPed samples enhanced by a factor ranging from 2.6 to 5 as compared to base material. ➢ The strain rate sensitivity of the FSPed material is 0.33 while for the as base material is 0.018. ➢ The deformation mechanism, is mainly controlled by solute drag creep in the fine-grained specimens, though the contribution of grain boundary sliding to the deformation process.

7	2009	Nasciment o.F., et al	Microstructural modification and ductility enhancement of surfaces modified by FSP in aluminium alloys	AA5083 and AA7022 Aluminium alloys in single and multiple passes Thickness - 10mm	➢ Smooth Concave Shoulder dia 15,17 19 mm 1.2) Scrolled profile Shoulder diameter - 17 mm ➢ Conical threaded pin dia. & length -8 & 6 mm 2,2) Threaded cylindrical pin dia. & length- 5& 4.6 mm 2.3) Semi-spherical pin dia. & length - 4 & 1.5 mm	➢ Effect of processing tools and parameters ➢ Microstructure and micro hardness ➢ Bending tests results	➢ A significant increase in formability of AA7022-T6 was obtained due to increase in ductility because of grain size refinement, increasing the maximum bending angle by 12 for the VFSP treatment and of 4 for the SFSP treatment ➢ In AA5083-O an increase of the maximum bending angle of 2.5 times for VFSP treatment and of 1.5 times for the SFSP treatment was obtained.
8	2011	A. Dolatkhah et al.	Investigating effects of process parameters on microstructural and mechanical properties of Al5052/SiC metal matrix composite fabricated via friction stir processing	AA5052 (125* 100 * 5 mm) Grooves with 2 mm depth and 1 mm width Tool H13 hot steel square pin profile, shoulder diameter of 18 mm, pin height of 3 mm and encircle diameter of 6 mm.angle 3°	➢ TS 40, 80 and 125 mm/min. ➢ TRS 700, 1120 and 1400 rpm	➢ Microhardness ➢ Microstructure ➢ Wear properties ➢ Friction properties	➢ The best distribution of SiC was obtained with tool rotational speed of 1120 rev/min and traverse speed of 80 mm/min. ➢ Nano-sized SiC powder FSPed Al 5052 showed the best result with average grain length of 243 lm to an ultrafine grained microstructure with average grain size of 0.9 lm. ➢ Wear rate was reduced about 9.7 times and micro hardness value was improved up to 55% as compared with received Al5052.
9	2011	Yadav.D., et al	Processing, microstructure and mechanical properties of nickel particles embedded aluminium matrix composite	Nickel particles were embedded into an Al matrix 1050 aluminium M2 tool steel	➢ Tool shoulder dia 12mm ➢ Tool pin dia 4mm ➢ Tool pin length 3.5mm ➢ Tool rotation speed of 1000rpm	➢ Microstructure ➢ XRD analysis ➢ Hardness ➢ Tensile properties	➢ Aluminium matrix composite with Ni particle embedded has been FSPed successfully in one step without any harmful intermetallic. ➢ The composite exhibits a 3 fold increase in 0.2% proof stress. ➢ EBSD and TEM analyses showed a continuous recrystallization process driven by dynamic recovery is operating during FSP.

10	2011	Bauri.R.,e t al	Effect of friction stir processing (FSP) on microstructure and properties of Al–TiC in situ composite	K2TiF6 salt & graphite powder corresponding to 5 wt.% of TiC were taken and mixed Thickness - 10mm Tool Material - M2 tool steel	➢ Tool Shoulder dia 12 mm. ➢ Tool pin dia 4 mm. ➢ Tool pin length - 3.5 mm. ➢ Tool rotation speed - 1000 rpm ➢ Tool traverse speed - 60 mm/min	➢ XRD phase analysis. ➢ Microstructure ➢ Hardness ➢ Tensile properties	➢ A single pass of FSP was enough to improve the grain distribution by breaking the particle segregation from the grain boundaries. ➢ Two passes of FSP showed the the complete homogeneous distribution and eliminats casting defects. ➢ The result also showed a significantly improvement in mechanical propertie due to improvement in the microstructure.
11	2017	Husain Mehdi et al	Mechanical properties and microstructure studies in Friction Stir Welding (FSW) joints of dissimilar alloy- A Review	AA5083 and AA7022 Aluminium, CY16, WC Tool, alloys in single and multiple passes Thickness - 10mm	➢ 2100 rpm and travel speed of 2.33 mm/s ➢ 650 rpm and a traverse speed of 203 mm/min ➢ Tool rotation rate of 300,700, 900 and 1100 rpm.	➢ UTS ➢ XRD ➢ Microstructure ➢ Micro-Hardness	➢ Grain structures had equiaxed and fine grains due to the recrystallization in the SZ while Nano-sized alumina particles distributed differently because of different stirring action. ➢ An average grain size as low as 1.46 µm was obtained for a particular process parameters setting.
12	2017	Husain Mehdi et al	Mechanical properties and microstructure studies in Friction Stir Welding (FSW) joints of dissimilar alloy- A Review	CY16, W-La, WC-411 tool	➢ 350 rpm and 15 mm/min ➢ 2236 rpm to 1500 rpm	➢ Mechanical Properties ➢ Wear Property ➢ Microstructure ➢ Macrostructure	➢ Welding parameter such as tool rotation, transverse speed and axial force have a significant effect on the amount of heat generated and strength of FSW joints. Microstructure evaluation of FSW joints clearly shows the formation of new fine grains and refinement of reinforcement particles in the weld zone with different amount of heat input by controlling the welding parameter
13	2017	Husain Mehdi et al	Influences of Process Parameter and Microstructural Studies in Friction Stir Weldingof Different Alloys: A Review	CY16, W-La, WC-411 tool	➢ 2236 rpm and travel speed of 2.33 mm/s ➢ 700 rpm and a traverse speed of 203 mm/min ➢ Tool rotation rate of 300,700, 900 and 1100 rpm.	➢ Mechanical Properties ➢ Microstructure ➢ Macrostructure ➢ Wear Properties	➢ The mechanical properties of welded joint by friction stir welding are largely dependent on the combined effect of both the composition of alloying element and processing parameter.

14	2012	S. Tutunchilar et al.	Simulation of material flow in friction stir processing of a cast Al–Si alloy	LM13 eutectic Al–Si as-cast alloy (100* 50*7 mm) Groove with the depth and width of 3 and 1 mm, resp. H13 steel. The shoulder and pin dia, and pin height were 18, 6, and 4 mm, resp.	➢ Graphite powder (with 5 lm particle size) ➢ TRS- 900 rpm ➢ TS- 50mm/min ➢ Tilt angle- 3 degree	➢ Temperature distribution ➢ Effective plastic strain ➢ Material flow in the weld zone	➢ Deep analysis of the material flow is used to get the material flow and it revealed that the material nearer the top surface was stretched toward the AS due to frictional force by the shoulder and the distance from top surface on increasing the final position of the material remains almost constant in the transverse direction despite of rotating around the pin. ➢ The result also shows a tunneling defect occurred at the AS and near the root of the SZ.
15	2012	Zohoor.M., et al	Effect of processing parameters on fabrication of Al–Mg/Cu composites via friction stir processing	Al5083 sheet using micro and nano-sized Cu particles Thickness - 5 mm Tool Material - H13 steel	➢ Tool shoulder dia 16 mm. ➢ Tool pin diameter 6 mm ➢ Tool pin height - 3.2 mm ➢ Tool rotation speed - 750 & 1900 rpm ➢ Tool traverse speed - 25 mm/min ➢ Tilt angle - 3°	➢ Microstructure ➢ XRD observations ➢ Tensile properties ➢ Micro hardness	➢ The result revealed that Cu particles improve the grain size on addition in AA 5083 and the best result was obtained with Nano-sized particles of Cu and at rotational speed of 750 rpm and the avg. grain size of 1.52 lm. ➢ Composites made of Nano size of Cu particles show higher Yield strength, elongation, UTS and hardness values as compared to received samples. ➢ XRD observations revealed that some reactions held between the elements of composite materials that increased upon the enrichment of tool rotational speed.
16	2013	Alaa Mohammed Hussein Wais et al.	Effect Of Friction Stir Processing On Mechanical Properties And Microstructure Of The Cast Pure Aluminum	Pure aluminium A cylindrical tool with threaded pin	➢ TS- 86,189,393 mm/min ➢ TRS- (560,710, 900) rpm	➢ Hardness ➢ UTS	➢ The heat generation increase with increase in rotational speed and decrease with increase in transverse speed. ➢ Hardness, impact measurements and tensile tests were taken across the process zone at room temperatures. ➢ The microstructure of the cast pure Al was refined greatly after FSP.

17	2013	Anvari.S. R., et al	Wear characteristics of Al–Cr–O surface nano-composite layer fabricated on Al6061 plate by friction stir processing	Al6061-T6 Thickness- 13 mm Tool Material - H13 steel	➢ Tool rotating speed (rpm) - 630 rpm ➢ Welding Feeds (mm/min) - 100. ➢ Tilt angle - 3^{0}	➢ Microstructure ➢ Wear behavior ➢ Worn surfaces characteristics	➢ The result obtain showed that the homogenous distribution of reinforcement particles over the nugget zone was produced by FSP without any defects. ➢ Wear resistance of Al6061-T6 reduced without reinforcement by FSP due to the loss of hardening precipitates.
18	2013	Miranda. R.M., et al	Reinforcement strategies for producing functionally graded materials by friction stir processing in aluminium alloys	AA5083-H111 alloy Thickness- 8 mm Reinforcing particles were SiC and Al2O3 of 35 and 45 m, Tool Material - H13 tool steel	➢ Tool threaded concave shoulder diameter (mm) - 19. ➢ Tool rotating speed (rpm) – 3000. ➢ Tool transverse speed 348 mm/min ➢ Downward force - 7 kN	➢ SiC reinforcements ➢ Deposition of SiC reinforcing particles by Friction Surfacing ➢ Comparison of deposition strategies	➢ Three strategies were used and surfaces analyzed to find the effect of deposition and processing on particle homogeneity and distribution. ➢ Three strategies were studied first ia a square shaped groove filled with reinforcement, second is the uniform layer deposition of particles with a non-consumable tool, and the last is of one consumable rod of aluminium drilled with holes along a radial line placed in different positions filled with reinforcing particles.
19	2014	S. Sahraeinej ad et al.	Fabrication of metal matrix composites by friction stir processing with different Particle sand processing parameters	Al5059 with Al2O3, SiC,and B4C with particle sizes of 130, 250, and 35nm respectively	➢ TRS- 56–1800 rpm ➢ TS- 11–2000 mm/min.	➢ Tensile strength ➢ yield strength 3 % elongation	➢ Yield strength of composites containing nano-scale Al2O3, SiC,and B4C increases 11%, 20%, and 38% increases , respectively compared to the received material. ➢ Al2O3 particles of size 4.3 μm employment achieved higher volume fractions which resulted the increase in yield strength by 32% compared to the base metal.
20	2014	Dhayalan. R., et al	Characterization of AA6063/SiC-Gr Surface Composites Produced by FSP Technique	Aluminium alloy (AA6063) plate & SiC and Gr as reinforcement Al/0.8 vol.% SiC, Al/0.8 vol.% Gr and Al/(0.4 vol.% SiC + 0.41vol.% Gr) Tool Material - High Carbon High chromium Groove dimension - 0.8 mm × 5 mm	➢ Tool pin profile - cylindrical threaded ➢ Tool Shoulder diameter - 18 mm ➢ Tool pin dia 6 mm ➢ Tool pin length 5.8 mm	➢ Microstructure ➢ Micro hardness	➢ The grain size refinement of the surface composite layer fabricated with SiC and Gr ceramic particulates by FSP. ➢ Microstructal investigation showed the homogenous distribution of the ceramic particulates in the stirred zone and good bonding between matrix materials.

21	2014	Salman.J., et al	Effect of Friction Stir Processing on Some Mechanical Properties and Microstructure of Cast (Al-Zn-/mg-Cu) Alloy	(Al-Zn-Mg-Cu) alloy prepared by mould casting process. Tool Material - alloy steel X12	➢ Tool Shoulder diameter - 16 mm ➢ Tool pin diameter 6 mm ➢ Tool pin length 6 mm ➢ Tool rotation speed - 450, 710 rpm ➢ Tool traverse speed - 116 , 189,303 mm/ min	➢ Mechanical properties ➢ Elongation (%) 1.2) Tensile Strength (MPa) ➢ Yield Strength (MPa) ➢ Microstructure analysis	➢ The significant grain refinement was controlled by the rotation speed and transverse speed the tool. ➢ HV variations are relatively small. ➢ Result showed the enrichment in tensile strength, yield strength and %elongation by FSP. ➢ The annealing process of the FSP showed the maximum tensile strength and %elongation.
22	2014	Resan.K., et al	Effect of Friction Stir Processing (FSP) to the Mechanical Properties of 7075-T73 Aluminum Alloys Plates Welded by Friction Stir Welding.	7075- T73 aluminum alloy Thickness - 3 Tool Material- tool steel X38	➢ Tool shoulder diameter (mm) 16 ➢ Tool pin diameter 5 mm ➢ Tool threaded pin length (mm) -2.9 ➢ Tool rotating speed (rpm) - 1500, 1700 , 1900 ➢ Welding Feeds (mm/min) 40	➢ Tensile Test ➢ Microstructure ➢ Micro Hardness	➢ The strength of 7075-T73 for FSW and FSP is highest at TRS of 1700 RPM and TS of 40 mm/min with the values of 390.35 MPa and 433.72 MPa respectively and 9.299% the efficiency improvement by FSP. ➢ The Vickers hardness is highest value of 135.7 and 143.1 for FSW and FSP respectively. ➢ The friction stir processing improved the micro structural properties at welding zones particularly at nugget zone and caused grain refinment of microstructure.
23	2015	C.N. ShyamKumar et al.	Effects of ball milling and particle size on microstructure and properties 5083 Al–Ni composites fabricated by friction stir processing	5083 Al alloy with fine Ni grain particle Size - 10µm Groove size width- 1mm Depth- 2mm length-50mm Tool 1) Pin length- 3.5 mm 2) pin dia- 5 mm	➢ RS range- 1000-1800 rpm ➢ TS range- 6-24 mm/min	➢ 0.2% proof stress ➢ UTS ➢ %EL	➢ The optimum parameters for FSPed AA 5083 with Ni partiucals was found of tool rotation speed of 1200 rpm and traverse speed of 24mm/min. ➢ Particle size refinement with 10 µm by ball milling showed uniform particle distribution. ➢ Higher ductility and strength, obtained in the as- received particle composite compared to the ball-milled particle composite.

24	2015	Devinder Yadav and Ranjit Bauri	Friction Stir Processing of Al-TiB2 In Situ Composite Effect on Particle Distribution, Microstructure and Properties	Commercially pure (99.5%) Aluminum Tool made of M2 steel 1) Shoulder dia. 15mm 2) Pin diameter- 5mm 3) Pin length of - 4 mm,	➢ Salt mixture of K2TiF6 and KBF4 (corresponding to 5 wt. % TiB2). ➢ TRS- 1000 rpm ➢ TS- 30 mm/min ➢ Double pass	➢ Hardness ➢ Proof stress ➢ UTS ➢ %elongation	➢ FSP caused significant grain refinement in the Al matrix and eliminate the casting defects . A narrow grain size distribution with more than 60% of the boundaries being high angle was observed after FSP. ➢ The strength and ductility of the composite was enhanced by 1.5 times and 11 to 19% respectively after FSP.
25	2015	Bauri.R.,et al	Effect of process parameters and tool geometry on fabrication of Ni particles reinforced 5083 Al composite by friction stir processing	Al 5083 alloy & Ni powder with average particle size of 70 µm. Groove of 1 mm in width, 2 mm in depth and 50 mm in length	➢ Tool Shoulder diameter - 15 mm. ➢ Tool pin dia. 5 mm. ➢ Tool pin length - 3.5 mm ➢ Tool rotation speed 1000, 1200,1500,1800 rpm ➢ Tool traverse speed 0.1,0.2,0.3,0.4,0.5mm/s	➢ Optimization of process parameters and effect of tool geometry ➢ Mechanical properties	➢ A minimum TRS of 1200 rpm and TS of 0.4 mm/s was necessary to incorporate Ni particles in AA5083. ➢ The geometrical features on the pin and shoulder played vital role to incorporate the Ni particles uniformly in AA5083. ➢ The grain size of the matrix from 25 µm to 3 µm was refined by dynamic recrystallization process using FSP. ➢ The hardness and strength of the composite material was improved significantly compared to received material and a high ductility was also obtained in the composite.
26	2015	Yuvaraj.N., et al	Fabrication of Al5083/B4C surface composite by friction stir processing and its tribological characterization	Al alloy 5083-O Groove (1 mm width and3 mm depth) Tool Material - H-13 steel Nano size B4C particle of 99.5%purity with the mean particle size of 30–60 nm	➢ Tool shoulder diameter (mm) - 18 ➢ Tool threaded pin length (mm) -5. ➢ Tool rotating speed (rpm) – 1000 ➢ Welding Feeds (mm/min) – 25. ➢ Tilt angle - 1.8^0	➢ Microstructural analysis. ➢ Hardness. ➢ Effect on the number of passes. ➢ Mechanical properties ➢ Wear properties	➢ AA5083 composite with B4C through FSP was fabricated by using micro and nano sized B4C particles. ➢ In the development of surface composites by FSP the number of passes and the size of reinforcement play a vital role. ➢ Mechanical properties of the FSPed surface composites were obtained by using micro-hardness and universal tensile tests.
27	2016	Rana.H.G.,et al	Fabrication of Al7075 / B4C surface composite by novel Friction Stir Processing (FSP) and investigation on wear properties	AA- 7075-T651 with reinforcement of B4C powder of 12 – 15 µm size contains 12 – 15 % of volume. Groove of 1.2(W) × 2.5	➢ Tool rotation speed - 545 rpm ➢ Tool traverse speed - 50 ,78 & 120	➢ Microstructure observations. ➢ Micro hardness ➢ Effect of TS on the Micro	➢ Micro hardness reduces on increasing tool traverse speed due to reduction in powder distribution and grain refinement because of reduction in stirring time. Highest hardness of 144 HV was obtained at

				(D) × 100(L) mm Tool Material - M2 grade steel	mm/min ➢ Cylindrical tool - no pin ➢ Tool tilt angle - 3^0 ➢ Tool Shoulder dia 18 mm	hardness	TS of 50 mm/min. ➢ Average hardness of composite material has been increased by 1.3 - 1.6 times of the base metal, which was 75 - 80 HV.
28	2016	C.N. Shyam Kumar et al.	Wear properties of 5083 Al–W surface composite fabricated by friction stir processing	5083 Al A groove of 1.5 mm in width, 2 mm in depth and 60mm long. 1) pin dia- 4 mm 2)shoulder dia - 15mm 3)pin length -3.5mm	Tungsten particles (Avg. size of 10 mm.)	wear resistance	➢ The 5083Al with tungsten composite layer revealed significant enhancement in the wear resistance as compared to base. ➢ The composite showed mild wear at all the three loads used where as a transition to severe wear at higher loads in case of the base and the composite material.
29	2014	Sahraeinejad et al.	Fabrication of metal matrix composites by friction stir processing with different Particles and processing parameters	Al5059 130 nm and 1.1 mm Al2O3, 250 nm SiC, and 35nm B4C. H13 die steel tool coated with ZrN/TiN	➢ TRS-56–1800 rpm ➢ TS- 11–2000 mm/min ➢ Tool probe profile ➢ Grrove depth- 2,4 mm ➢ Shoulder dia.- 10,12,15mm ➢ Pin length- 2,2,2,3.8,4 mm	➢ Micro hardness ➢ YS ➢ UTS ➢ %EL	➢ Homogeneity in the upper and lower portions of the stir zone was more With increasing the number of FSP passes and distribution of reinforcing particles was much. ➢ Composite samples of B4C reveals the highest tensile yield strength with the reduction of ductility of 2.5% elongation.
30	2014	Sun.N., Apelian.D ,et al	Composite fabrication in cast Al A206 via friction stir processing	sand cast A206 alloy 1567*660*6 cm. HAAS M3	➢ Tool shoulder diameter - 16 mm ➢ Probe length - 3.2 mm ➢ Tilt angle - 3 tool ➢ Tool Rotating speed - 1000 rev /min ➢ Tool traversing speed 50 mm /min.	➢ Fabrication ➢ SEM/EDS analysis of Ta–Al composite layer ➢ Images (SEM) of Ta–Al composite layer ➢ Fabrication using DRA	➢ The good distribution of reinforcement particles is recognized to the following: ➢ Sufficient material movement ➢ Encapsulation of reinforcement (iii) sufficient contact between the reinforcement and the tool. ➢ Multi-passes in FSP could improve the dispersion of the reinforcement. ➢ Fabricating composites using DRA also showed that the dispersion of reinforcement was affected by number of the stirring passes and the location of the DRA preform.

31	2013	Mahmoud .E. R. I.,Ikeuchi. K., et al	Fabrication of SiC particle reinforced composite on aluminium surface by friction stir processing	Pure Al A1050-H24 plates of 5 mm thickness SKD61 Groove of 2–3 mm width and 1.5–2 mm depth at a density of 1.76106 g m23	➢ Tool angle - 3° ➢ Tool rotational speed - 1000–3000 rev / min ➢ Tool travel speed - 0.83–3.33 mm/s ➢ Tool shoulder diameter - 14 mm. ➢ Tool probe diameter - 5mm ➢ Probe length - 3.3 mm.	➢ General features of stir zone. ➢ Effect of amount of SiC powder ➢ Improvement in SiC particle dispersion by optimising rotation speed. ➢ Groove position relative to tool probe	➢ A 2 mm thick Al cover sheet can be used to prevent the SiC particles in the groove from going during the FSP. ➢ The SiC particles were dispersed homogeneously and more widely in the nugget zone at TRS not more than 1500 rpm 3) At higher TRS although process defects or even nugget corruption occurred at aTRS of 1000 rpm or less depending on the size of groove and penetration of the pin.
32	2015	Sharma.V. ,Prakash. U., et al	Friction Stir Processing Strategies for Uniform Distribution of Reinforcement in a Surface Composite	A 150 *60 *6.3mm plate of AA5083 H13 steel tool (52 HRC)	➢ Tool angle - 2.5° ➢ TRS -1000 and 2000 rpm ➢ TS -25 and 40mm/min ➢ Tool concave shoulder shoulder diameter - 21 mm ➢ Square probe diameter - 4 mm	➢ SEM micrographs of surface composites ➢ Optical micrographs	➢ The development of Bands of reinforcement particles occurs at the lower rotational speeds of 1000 and 1400 rpm, whereas no development of such bands occurs at a higher rotational speed of 2000 rpm. ➢ Bands of reinforcement particles still existed after tool offset passes, but their position shifted according to the tool offset.
33	2017	Behnagh. R., et al	Mechanical Properties, Corrosion Resistance, and Microstructural Changes during Friction Stir Processing of 5083 Aluminum Rolled Plates	AA5083 6mm thick Carbide-tungsten Tool	➢ Tool angle 2 ° ➢ TRS -710 to 1400 rpm ➢ TS -12.5 to 63 mm/min ➢ Shoulder diameter - 11.5mm ➢ Tool taper probe dia 3mm	➢ Microstructural Characterization ➢ Hardness ➢ Wear Behavior ➢ Corrosion Behavior	➢ The Nugget zone contained fine equiaxed and homogeneous grains with avg. size of 3 mm. ➢ The hardness in the FSPed zone was increased and approximate was 93 HV. ➢ FSP was found to be beneficial tool for improving wear resistance.

34	2013	Ebnonnasir.A.,et al	Novel artificial neural network model for evaluating hardness of stir zone of submerge friction stir processed Al 6061-T6 plate	Al 6061-T6 plate. Thickness of the plate was 13 mm H-13 tool steel	➢ Tool angle 2° ➢ TRS -50 to 2000 rev/ min ➢ TS -12 and 800 mm /min ➢ Tool shoulder diameter -20 mm. ➢ Tool cylindrical pin dia.- 4 mm ➢ Tool cylindrical pin length - 6 mm	➢ Model performance Microstructure studies ➢ Comparison between predicted and measured values for all datasets	➢ Prediction of avg. hardness of stir zone of Al 6061-T6 alloy done by a neural network model. ➢ TRS and TS were used as input parameters for the model. ➢ The results revealed that the network is capable with a relatively small error for the prediction of average hardness of stir zone from input parameters.
35	2015	Puviyarasan.M., et al	Microstructural evolution and mechanical behaviour of AA6063/SiCp bulk composites fabricated using friction stir processing*	AA6063 alloy in T6 dimensions= 100 × 50 × 10 mm SiC particles of 3 µm and 99.9% purity	➢ Tool angle -3° ➢ Tool rotational speed -1000 rpm ➢ Tool travel speed -30, 40 and 50 mm/min ➢ Tool flat shoulder diameter -18 mm. ➢ Tool cylindrical pin dia. 6 mm	➢ Evaluation of tensile properties ➢ Hardness measurements	➢ The avg. micro-hardness was increased by 22% compared with the received material of 82Hv after FSP. ➢ The microstructural revealed that the SiC particles had well bonding with the AA6063 matrix and were well distributed up to 13 mm from the centerline of the tool movement. ➢ The mechanical properties such as yield strength, UTS and ductility decreases of bulk composite of AA 6063/SiC after FSP.
36	2007	SU.J.Q., et al	Grain refinement of aluminum alloys by friction stir processing	7075-T6 Al	➢ Tool angle 3° ➢ TRS 1000 rpm ➢ TS -12 cm/min ➢ Tool shoulder diameter -9 mm. ➢ Cylindrical pin diameter - 3 mm ➢ Tool cylindrical pin length - 1.9 mm	➢ Overview of as processed microstructures. OIM observation ➢ Microstructure characteristics	➢ With rapid cooling during FSP successfully refined the grain structures to the nano-scale in AA7075. ➢ Small grains of 100, 180, 300 and 500nm were obtained by controlling the cooling rate. ➢ Recovery structures and Dislocations were observed in the larger grains samples.

37	2015	Patel.V., et al	Influence of Friction Stir Processed Parameters on Superplasticity of Al-Zn-Mg-Cu Alloy	Al 7075-T651 6.35-mm-Thickness Heat-treated tool steel (M2 grade)	➢ Tool angle - 2° ➢ TRS -765, 1070,1500, rpm ➢ TS -31.5,50,78 mm/min ➢ Tool shoulder diameter -20 mm. ➢ Tool cylindrical tapered left-hand threaded pin diameter - 3 mm	➢ Microhardness ➢ Optical micrographs of FSP samples.	➢ The average hardness in the stir zone of AA 7-75-T651 is strongly dependant on low heat input values having higher tool rotation speed and traverse speed. ➢ On increasing tool rotation speed grain size decreases due to the high heat input, which led to grain growth at high tool rotation speed. ➢ Superplastic behavior was observed on TRS of 765 rpm, TS of 31.5mm/min and 2 with uniform elongation in the gage length.
38	2016	Beygi.R., er al	Friction Stir Processing of Al with Mechanically Alloyed Al-TiO2-Graphite Powder: Microstructure and Mechanical Properties	Al-1050 plates with dimensions of 5 mm* 60 mm* 130 mm Groove with dimensions of 1 mm93 mm	➢ Tool rotational speed 950 rpm ➢ Tool travel speed - 37.5 mm/min	➢ SEM image of the as-mixed micro-size powder ➢ Micro hardness	➢ Al/TiC-Al2O3 nanocomposite can be obtained by 60-h ball-milled by FSP with Al- TiO2-graphite powder mixture. ➢ Previous ball milling process facilitates the reactions during FSP which would not occur using as-mixed powders.
39	2016	Li. W., et al	Effect of Tool Rotation Speed on Microstructure and Microhardness of Friction-Stir-Processed Cold-Sprayed SiCp/ Al5056 Composite Coating	Al5056 powder as matrix with 15% volume fraction of SiC powder as reinforcement	➢ Tool angle - 2.5° ➢ TRS - 600 or 1400 rpm ➢ TS -100 mm/min ➢ Tool concave shoulder dia. - 10 mm	➢ Macrostructure of FSPed Coating ➢ Microstructure Characterization	➢ No undesirable interfacial reactions observed between the matrix and reinforcement During FSP, but a reduction of coating thickness from 665 lm to 632 lm at TRS of 600 rpm or 415 lm at TRS of 1400 rpm was observed due to the severe stirring effect.
40	2016	Yuvaraj.N ., et al	Wear Characteristics of Al5083 Surface Hybrid Nano-composites by Friction Stir Processing	Aluminium alloy of 5083-O rolled plate of 8 mm thickness H-13 hot working tool steel nano sized B4C particles of 99.5 % purity with the particle size of 30–60 nm	➢ Tool angle 2.5° ➢ Tool rotational speed -1000 rpm ➢ Tool travel speed -100 mm/min ➢ Tool shoulder diameter - 18 mm ➢ Tool threaded pin diameter & length - 6 mm & 5 mm	➢ Particle Distribution ➢ Microhardness ➢ Tensile Test ➢ Wear Properties	➢ Mono and hybrid FSPed composite samples showed uniform dispersion of B4C and TiC particles in the matrix and Exhibited higher hardness and strength compared with FSPed samples with received material. ➢ Lower ductility observed when compared to Al–TiC and Al–B4C/TiC nano reinforced composites.

3. Conclusions & Recommendations

1. The surface composite layer of Nano reinforcement particles by friction stir processing on magnesium alloys improves tensile behavior, hardness, corrosion resistance, percentage and wear resistance behavior of the workpiece material.
2. The friction stir processing with multiple passes could effectively cure the onion premature splitting by accumulating a higher degree of strain and the initial grains gets fully recrystallize and to improve the microstructure.
3. Increasing the tool rotational speed results greater heat input and increases grain size of the metal alloy and simultaneously more shattering effect of rotation, results a better distribution of nano particles.
4. Water cooling durin friction stir welding on magnesium MZ91 enhances the hardness and reduces the final grain size, while the amount of oxide particles in the processed area increases.

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