A Review on Friction Stir Processing of Surface Modified Copper-Nickel Composites

T. Velmurugan[1], V. Sanjay[2], A. Suryasubramanian[3], M. Thirulogasundar[4]
[1]*Assistant Professor, Dept. of Mechanical Engg., Sri Ramakrishna Engineering College, Coimbatore, India*
[2,3,4]*Student, Dept. of Mechanical Engg., Sri Ramakrishna Engineering College, Coimbatore, India*

***Abstract*: Friction stir processing is one of the most efficient techniques for microstructure refinement. The objective of this present research is to produce reinforced 90/10 Cupro-Nickel surface composites with different carbide-based ceramic particles through FSP and study the relationship of its dynamic parameters including tool rotational speed, tool traverse speed, and width of the groove over the surface behavior. Analysis of the models showed that the FSP parameters; traverse speed, rotational speed, and groove width have a significant influence on both sliding wear and micro hardness of developed surface composite. And then, tool rotational speed and tool traverse speed, simultaneously control dispersion of reinforcement in the surface.**

***Keywords*: Friction stir processing, cupro nickel, surface composite microstructure, microhardness, wear, stirzone.**

1. Introduction

Cupronickel (90% Cu & 10% Ni) alloy is one of the most commonly used materials for marine applications such as condenser, heat exchanger, desalination plants and seawater piping [1].The alloy is extremely prone to failure where a greater resistance to flow conditions is needed and hence a stream of researchers are exploring and developing tribologically and mechanically superior ceramic particulate reinforced composites, To meet such demanding mechanical and surface quality requirements, materials can be subjected to surface modification techniques. One of the recent processes used to modify the surface quality of the material is Surface Metal Matrix Composites (SMMC), that capable to enhance wear resistance, hardness and thermal/electric conductivity [2, 3]. But, the main challenge is to improve the surface properties without affecting the quality/base properties of the parent metal [4, 5]. To overcome the limitation of the copper-based alloy, various hardening mechanisms and reinforcement of hard particles as the second phase are used [6]. The friction Stir processing technique is extensively used for both surface modification and also to develop bulk composites [8]. In conventional FSP, a groove or groove is made to the required width and depth in the base metal and filled with ceramic particulates. The FSP tool is then plunged and moved (traverse direction) over the groove to disperse the ceramic particles by plastic deformation and form surface composite to enhance the surface properties. [9, 10]. In Friction Stir Process, there are a number of crucial factors such as tool traverse speed, rotational speed, geometry, tilt angle, material chemistry, etc that influence the performance of the processed surface [11]. Those FSP factors decide the mechanical properties like hardness, wear resistance, strength and fatigue life of the composite.

2. Survey on methodology

To protect metals from corrosion, the base material must be protected from the environment otherwise it should be coated with protective films or coatings, which protect the base material from corrosion [12], [13]. Several techniques are available for deposition of nano coatings on metals such as physical vapor deposition (PVD), chemical vapor deposition (CVD), Plasma spraying, sol-gel, electrochemical deposition, and friction stir processing. Compared to other metalworking techniques, FSP has distinct advantages. FSP is a solid-state processing technique with one-step processing which achieves microstructural refinement densification and homogeneity. The microstructure and mechanical properties of the processed zone can be accurately controlled by optimizing the tool design, FSP parameters, and active cooling/ heating. The heat input during FSP comes from friction and plastic deformation, which means FSP is a green and energy-efficient technique without deleterious gas, eradiation, and noise. FSP does not change the shape and size of the processed components. The advantages of the FSP technique compared to these other processing techniques are summarized. First, FSP is a relatively simple processing technique with a one-step processing that produces a fine-grained microstructure. Other processing techniques are relatively complex and time-consuming and lead to increased material cost. Thus, from the data gathered form the table below and by comparing the results with other processes and by considering time factor and cost. Friction stir processing, have been selected as a suitable method to enhance the surface hardness of the metal.

Table 1
Survey on methodology

S. No.	Journal name	Author & publication Year	Abstract	Testing	Result
1	FSP of a cold sprayed AA7075 coating layer on the AZ31B Substrate	F.Khodabakhshi, B. Marzbanrad, L.H. Shah, H.Jahed, A.P.Gerlich 22 Oct 2017	Cold Spraying of aluminum-zinc alloy (AA7075) on the surface of AZ31B magnesium alloy.Further FSP was applied to improve the structure and integrity of the cold sprayed layer.	NANOVEA M1 Hardness Indenter is used. Vickers hardness number of around 74 HV (before FSP) and 135 HV(after FSP)	cold spray deposition and FSP were applied as two complementary processes to produce a dense, homogenous and hard coating metal layer (AA7075) on the surface of another metal substrate (AZ31B).
2	FSP tool design on microstructure and superplastic behavior of Al-Mg alloys	M.A. García-Bernal, R.S. Mishra, R. Verma, and D. Hernández-Silva 30 may 2016	The effect of tool design on the superplastic behavior of friction stir processed Al-Mg alloys has been investigated. The alloy was friction stir processed at 400 rpm and 0.42 m/s. Four different tools were used and compared. The pin was right-handed screw type in all cases. tool tilt angle and plunge depths were 2.5º and tool height plus 0.4 mm	The microstructure was observed by optical, scanning and transmission electron microscopy on the transverse cross-section of the FSP zone. The samples for optical analysis were etched using Keller's reagent to reveal grain boundaries	Bigger Shoulder area of the tool has generated a stable microstructure at a high temperature, allowing a greater concentration of heat during the FSP, which leads to a larger plastic deformation of the processed material
3	Fabrication of AA7005/TiB2-B4C surface composite by FSP	Nithin Kumar pal, R.P. Pandey 1 Aug 2018	surface composites with different weight fractions of TiB2 and B4C particles were processed by FSP. The surface hardness of the composite was found to be nearly 70 HV higher than base alloy.	To test the Fine grain Size, higher Hardness, Ultimate strength, low wear rate, mechanical properties.	The surface hardness of the base alloy, FSP sample, and 25B4C -75TiB2, 50B4C-50TiB2, and 75B4C - 25TiB2 composite is found to be 90,120 and 150 HV, respectively.
4	Influence of FSP conditions on the manufacturing of Al-Mg-Zn-Cu alloy/boron carbide surface composite	Harikrishna Rana,Vishvesh Badheka 17 Jan 2018	Surface metal matrix composites were synthesized via FSP on the surface of aluminum alloy 7075 (AA 7075) sheets by incorporating B4C particles (B4CP). A mixture prepared from methanol and B4Cp was filled in a zig-zag array of 2×2mm blind holes made on the substrate plate.	Wear tests for all the SMMCs along with parent metal (PM) and samples FSPed without B4CP were carried out using pin-on-disk tribometer.	The addition of B4C particles was witnessed with fine B4C particles, owing to a higher number of preferential sites for nucleation and pinning at Grain Boundaries. The grains initially sizing 220μm was reduced down to 7μm, in the processed zone of composites resulting from FSP
5	Microstructural evaluation and mechanical properties of FSPed ZrB2/6061Al nanocomposites.	Z.Y.Zhang, R.Yang, Y.Li, G.Chen,Y.T.Zhao,M.P.Liu 19 May 2018	Homogeneously dispersed ZrB2 nanoparticles and fine-grained structures were Successfully achieved by FSP of 0-2 vol% ZrB2/6061Al nanocomposites. The effects of ZrB2 additions on the microstructures and tensile properties were investigated.	Microstructural analysis was carried out by SEM, EBSD detector.	The formations of ultrafine grained structure and uniform reinforcements were accompanied with remarkable improvement in the yield strength and elongation

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6	Through thickness FSP; a low-cost technique for fusion welds repair and modifications in the AA6061 alloy	Saeed Aliakbari, Mostafa Ketabchi, Seyyed Ehsan Mirsalehi 7 Aug 2018	Gas metal arc welded joints of the AA6061 alloy were subjected to the friction stir processing technique in the through-thickness direction to modify the surface and the bulk of the welds	Hardness survey analysis was done at the middle of the sample's cross-section, using Vickers indenter with 1 -kg load for 10 s.	Weld defects like gas porosity, lack of fusion and micro shrinkage were also eliminated in full thickness of the welds. Tensile strength and elongation were considerably enhanced by Through-thickness FSP
7	High-efficiency dispersal and strengthening of graphene-reinforced aluminum alloy composites fabricated by powder metallurgy combined with friction stir processing	Z.W. Zhang, Z.Y. Liu, B.L. Xiao, D.R. Ni, Z.Y. Ma 14 April 2018	Graphene nanoplatelets reinforced 2009Al (GNP/2009Al) composites were fabricated by a combination of powder metallurgy and subsequent multi-pass FSP.	GNP distributions in composites under various fabrication conditions were examined using optical microscopy, field emission scanning electron Microscopy, and transmission electron microscopy. The Vickers microhardness (HV) of composites was measured using a Leco-LM-247 AT indenter under a load of 1000 g with a dwell time of 30 s.	Strength calculations based on load transfer indicated that the high-efficiency strengthening of composites was mainly attributed to the large specific surface area of uniformly dispersed GNPs.
8	High-Temperature Characteristics of Al2024/SiC Metal Matrix Composite fabricated by Friction Stir Processing	Ali Hosseinzadeh and Guney Guven Yapici 20 June 2018	Friction stir processing (FSP) is used for the synthesis of an aluminum metal matrix composite (MMC) reinforced by SiC particles. MMC specimens with reinforced. Microstructures exhibited significant improvement in hardness (near 50%).	Scanning electron microscopy studies aimed at investigating the fracture mechanisms and SiC particle distribution, were conducted in a JEOL SEM equipped with an energy dispersive X-ray spectroscopy detector.	At the stir zone (SZ), the material is under severe plastic deformation causing the formation of fine grains with high angle boundaries. With respect to the grain refinement, the density of grain boundaries increased and the average grain size decreased from 22µm down to 2.3µm. Improved elongation levels reaching 10% and 15% at ambient and high-temperature conditions.
9	Effect of friction stir processed microstructure on tensile properties of an Al-Zn-Mg-Sc alloy upon subsequent aging heat treatment	Indrajit Charit, Rajiv S. Mishra 2 Nov 2017	An as-cast Al-Zn-Mg-Sc alloy was friction stir processed varying tool related parameters, yielding microstructures with different grain sizes (0.68, 1.8 and 5.5 µm).	Run-1 will designate the FSP run made with the plunge depth of 6.4 mm, and Run-2 with 7.1 mm. Notably, in all these runs, the tool axis was kept at an angle of 2.5◦with the vertical. However, Run-3 was performed with a smaller tool but with the same tool rotation rate and traverse speed.	The microstructure of the Run-1 sample contains porosity-free grains with an average diameter of 1.8 µm, the mean grain sizes of Run-2 and Run-3 samples were measured to be 5.5 µm and 0.68 µm. FSP improved the tensile properties of a cast Al-Zn-Mg-Sc alloy, resulting in the yield strength (301–383MPa), ultimate tensile strength (416–482 MPa), and elongation to fracture (22.0%–26.4%) over those of the as-cast alloy (fracture strength of 233 MPa with no ductility).

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10	Modification of a cold sprayed SiC/Al5056 composite coating by friction stir processing	Chunjie Huang, Wenya Li, Zhihan Zhang, Maosen Fu, Marie-Pierre Planche, Hanlin Liao, Ghislain Montavon 9 April 2016	The SiC particles reinforced Al5056 composite coating was deposited onto a pure Al substrate by cold spraying of a powder mixture having 45 vol.% SiC, and then modified by (FSP)with a threaded stir tool probe aiming to study the changes in microstructure and tribological behavior of the composite coating before and after the FSP treatment.	The stir zone was cross-sectioned perpendicular to the processing direction for Metallographic analysis using an electrical discharge cutting machine. The phase compositions of the coatings before and after FSP treatment were identified.	The Al matrix particles are substantially refined to fine and equiaxed grains. The average size of SiC particles in the as-sprayed coating is 12.2 μm, while the SiC particles in the FSPed coating have a finer size of 4.4 μm due to the severe stirring effect.
11	Formability of friction stir processed low carbon steels used in shipbuilding	D.M. Sekban, S.M. Akterer, O. Saray, Z.Y. Ma, G. Purcek 13 November 2017	The stretch formability of a low carbon steel processed by friction stir processing (FSP) was studied under biaxial loading condition applied by a miniaturized Erichsen test. FSP slightly decreased the stretch formability of the sample to 2.66 mm.	Erichsen test technique was used for evaluation of stretch formability of the samples under biaxial strain conditions before and after FSP. SEM was used for investigation of the dome free surfaces of stretched FSPed and unprocessed samples	Both yield and tensile strength values increased from 256 MPa and 435 MPa to about 334 MPa and 525 MPa, respectively. In addition, FSP decreased slightly the elongation to failure and uniform elongation from 44% and 18% to about 32% and 14%, respectively.
12	Grain size dependence of fatigue properties of friction stir processed ultrafine-grained Al-5024 alloy	Shivakant Shukla, Mageshwari Komarasamy, Rajiv S. Mishra 11 December 2017	The objective of the present study was to examine the effect of grain size on the fatigue properties of the 5024Al alloy. Two different grain sizes obtained by varying the FSP parameters will be referred to as UFG410 and UFG210 alloys	Fatigue properties were investigated using a fully reversible bending fatigue testing machine. Microstructural evolution during fatigue was analyzed by carrying out interrupted fatigue testing with subsequent orientation imaging microscopy	The results indicate that FSP can be utilized as an effective route to obtaining stable UFG microstructure. A fractographic study was done to understand the effect of microstructure on fatigue crack initiation and propagation rates.
13	Effect of Nano-Al2O3 Particles and Friction Stir Processing on 5083 TIG Welding Properties	M. Kianezhad, A. Honarbakhsh Raouf 9 Aug 2018	Welding fillers containing various amounts of 30 nm nano-Al2O3 particles were fabricated using friction stir processing and used to improve the mechanical properties of the welding zone. To achieve a uniform Distribution of the nanoparticles, friction stir processing was applied to the welding zone.	Vickers micro-hardness test was performed on one test specimen for each sample with a load of 25 g and dwell time of 10 s. the specimens were etched with 50ml of Poulton's reagent solution for 55 s in order to observe grain boundaries	By increasing the amount of nano-Al2O3 particles in the welding zone up to 1.5 Vol.%, the strength of the FSP-ed specimen increased. Applying FSP to the welding zone led to an improvement in tensile properties. In comparison with the “Simple weld” specimen, maximum improvement of yield strength (29%) and tensile strength (about 17.5%) of the welded parts was attained in the FSP-ed specimen containing nanoparticles in the welding zone (“1.5+FSP” specimen).

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14	Microstructure and wear behavior of aluminum nitrate reinforced surface composite layers synthesized using friction stir processing on cupro substrate	S.Saravanakumar, S.Gopalakrishnan, I. Dinaharan, K. Kalaiselvan 11 May 2017	Aluminum nitride (AlN) is a potential ceramic particle to improve the wear resistance of cup surface. The present work is focused on synthesizing Cu/AlN (0,6,12,18 vol.%) Cupromatrix composites on pure cupro substrates through FSP. AlN particles were compacted into grooves machined on the surface of the cuproPlates. The depth of the groove was 4 mm.	The microhardness was measured using a microhardness tester at 500 g load applied for 15 seconds at various locations within the stir zone. The wear test parameters were sliding velocity– 1.5 m/s, normal force–30 N and sliding distance–3000 m tested by pin-on-disc wear apparatus	The wear rate of Cu/AlN CMCs decreased with the increased volume fraction of AlN particles. The wear rate was estimated to be 248 x 10-5 mm3/m at 0 vol.% and 174 x10-5 mm3/m at 18 vol.%. The improvement in wear resistance was correlated to improved hardness, reduced contact area and low coefficient of friction.
15	Ultra-grain refinement and enhanced low temperature superplasticity in a friction stir processing Ti-6Al-4V alloy	Wenjing Zhang, Hua Ding, Minghui Cai, Wenjing Yang, Jizhong Li 2 March 2018	An ultrafine microstructure consisting of α grains (~0.51μm) and a small amount of β phase was successfully achieved in a friction stir-processed (FSPed) Ti-6Al-4V alloy.	The microstructure characterization was carried out by SEM, TEM, XRD. Tensile specimens with a gauge length of 4 mm and cross section of 2×0.85 mm were cut from the SZ, and superplastic tensile testing was performed at temperatures of 550, 600 and 650. To reach the thermal equilibrium, all the specimens were held for 5 min at the desirable testing temperature prior to tensile testing	All tensile specimens exhibited excellent LTSP and a maximum elongation of 1130% was achieved at 600°C and 3×10-4 s-1.
16	Evolution of microstructure and mechanical properties of Fe-24Ni-0.3C TRIP steel during friction stir processing	H.G. Tehrani-Moghadam, H.R. Jafarian, M.T. Salehi, A.R. Eivani 30 January 2018	The effect of friction stir processing (FSP) by various transverse welding speeds of 50-150 mm/min on mechanical properties and microstructure in a Fe-24Ni-0.3C TRIP steel was investigated. The results showed that the defect fewer FSPed specimen was obtained at the transverse speed of 100 mm/min.	Microstructural analysis was carried out by SEM, EBSD detector. It was found that by increasing the transverse speed, more significant grain refinement was observed in the stir zone.	The FSP processed samples illustrated higher yield strength in comparison to the starting material which was increased from 145 MPa to 210 MPa, is due to effective grain refinement.
17	Improvement the surface structure of Nickel-Aluminum Bronze (NAB) alloy using Al2o3 nanoparticles and FSP method	Keshavarz, Abbasi Khazayi 2016	For surface hardening and elimination of defects caused by the casting alloy, FSP is applied to NAB. In this paper, alumina oxide (Al2O3) nanoparticles are used in order to create a composite layer on the NAB alloy by FSP.	Sample 1 is a molten sample. Sample2 is processed by FSP. Sample3 was considered in the production of surface Nanocomposite by using FSP and nanoparticles of Al2O3 in size of 20 nanometers. Hardness-meter Vickers was used and the hardness test was performed for each three samples	The hardness of self-alloy was increased by the friction-stir process and to reach 203 Vickers. By applying Friction-stir process, the surface microstructure is improved, molten damages and partings are deleted and mechanical properties are decreased

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18	Ultrasonic Cavitation Erosion-Corrosion Behavior of Friction Stir Processed Stainless Steel	Karthikeyan Selvam, Priya Mandal, Harpreet Singh Grewal, Harpreet Singh Arora 24 February 2018	Cavitation erosion remains the primary cause of material degradation in fluid machinery components operating at high speed. They demonstrate a novel pathway to control cavitation erosion-corrosion by tailoring the surface properties using submerged friction stir processing (FSP), a severe plastic deformation process.	To understand the corrosion behavior, standalone electrochemical corrosion tests were done in 3.5% NaCl solution. Individual roles of cavitation, corrosion and synergistic effects were analyzed	The processed sample showed four to six times better performance than as-received steel. The processed samples showed higher strength and quicker passivation kinetics.
19	Influence of friction stir processing parameters on surface modified 90/10copper-nickel composites.	G. Suganya Priyadharshini, R. Subramanian, N. Murugan & R. Sathiskumar 28 May 2017	To produce reinforced 90/10cupro-Nickel surface composites with different carbide-based ceramic particles through FSP and study the relationship of its dynamic parameters including tool rotational speed, tool traverse speed, and width of the groove over the surface behavior.	Analysis of the developed models showed that the FSP parameters; traverse speed, rotational speed, and groove width have a significant influence on both sliding wear and microhardness of developed surface composite.	The estimated tendency on the properties of CuNi SCL as a function of tool rotational speed for a constant set of traverse speed of 30 mm/min, a groove width of 0.7 mm and ceramic particle of B4C was predicted. The wear rate of the CuNi increases as tool rotational speed is raised from 1000 to 1400 rpm. The mechanism involved in microhardness, wear resistance and the surface area increment is due to strain hardening and particle distribution.
20	Effects of friction stir processing on hydrogen storage of ZK60 alloy	E.P. Silva, D.R. Leiva, H.C.Pinto, R. Floriano, A.M. Neves, W.J. Botta 25 April 2018	The possibility of using FSP with subsequent filing as a mean to obtain materials with suitable properties for use as energy carriers with enhanced kinetics and better oxidation resistance in shorter processing times.	For microstructural characterization, a scanning electron microscope is used. The kinetics of hydrogen absorption and desorption were measured using a homemade Sievert's type apparatus with calibrated volumes	FSP processing of ZK60 alloy promotes ultra-refinement and fully recrystallization with a randomly orientated microstructure, reducing grain size from more than 150 mm to 1e2 mm, and in addition breaking and pulverizing the intermetallic phases.
21	Laser deposition technology assisted by friction stir processing for preparation of nanostructured FeCr–Si alloy layer	Siyao Xiea, Ruidi Lia, Tiechui Yuan,, Chao Chena, Mei Zhang, Minbo Wanga, Peng Caob. 9 January 2018	Laser deposition technology assisted by FSP to eliminate these common metallurgical defects. A Fe–Cr–Si alloy was selected as a representative material. Severe plastic deformation caused by FSP has refined the coarse solidification microstructure into ultrafine grained.	Microstructures were observed by SEM EDS. Microhardness measurements across the surface layer were performed using a micro-Vickers hardness tester.	FSP was able to refine the solidified coarse grains to ultrafine or even nano-sized grains. Stacking fault and twinning are the two main deformation mode. Grain refinement is achieved mainly by grain fragmentation and recrystallization.

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22	Development of surface composite based on Al-Cu system by FSP: Evaluation of microstructure, formation mechanism and wear Behavior.	Guoqiang Huang, Wentao Hou, Junping Li, Yifu Shen 3 March 2018	FSP was used to fabricate in-situ surface composite based on Al-Cu system on 1060 Al substrate. The effects of the number of FSP passes on phase compositions, microstructure and wear behavior of the resulting surface composites were investigated.	The microstructures of the prepared samples were observed by OM, SEM coupled with an energy dispersion analysis, electron backscattered diffraction and transmission electron microscope. X-ray diffraction (XRD) was used for phase identification. wear testing, surface wear morphologies were observed by SEM.	Improvement in microhardness and wear resistance as compared with as-received Al. Increasing the number of FSP passes is favorable to the further improvement in the microhardness and wear resistance of the FSPed composite layers. The maximum microhardness was achieved in the 5-pass FSPed AMC layer, reaching a level as high as ~75 HV.
23	Strengthening and toughening mechanisms of CNTs/Mg-6Zn composites via FSP	Yongxian Huang, Junchen Li, Long Wan, Xiangchen Meng, Yuming Xie 4 July 2018	High strength and toughness carbon nanotubes (CNTs) reinforced Mg-6Zn composites were fabricated by stirring casting integrated with FSP. The strengthening mechanisms of the CNTs/Mg-6Zn composites were expounded by the characterization of the microstructural evolution and the mechanical properties.	Vickers micro-hardness tests were performed with a load of 200 g and a dwell time of 10s. The tensile tests were Conducted using an INSTRON 5965 mini tester and the pictographs were observed by SEM.	The YS, UTS, and El. of the FSPed composites reached 17MPa, 330MPa and 15%, with a significant enhancement than that of the as-cast Mg-6Zn alloy. Thus, stirring casting and subsequent FSP is proved to be an effective and feasible method to fabricate high strength and toughness CNTs/Mg composites.
24	Effect of processing parameters on the fabrication of Al-Mg/Cu composites via friction stir processing	Mehdi Zohoor, M.K. Besharati Givi, P. Salami, 7 March 2012	The production of AA5083 aluminum alloy with reinforced layers using superparticles via FSP was discussed. Effects of rotational speed, FSP pass numbers, and Cu particles' size were investigated on microstructure, particles distribution pattern and microhardness. Cu particles were embedded and compressed into the groove.	Microstructural characterization was performed through OM and SEM. XRD was utilized to identify the phases in the specimens. The microhardness values of the surface composite layers were measured perpendicular to the processing direction using a load of 200 g for 15 s	Addition of Cu particles improved the grain size and the best result was gained with nano-sized particles. Composites with nanosized Cu particles show higher YTS, UTS, elongation and hardness values than the as-received samples.
25	TEM characterization on amorphous/nanocrystalline/nano-twin of Ti-6Al-4V/Ag nanocomposite processed by friction stir processing	Lechun Xie, Liqiang Wang, Kuaishe Wang, Guilin Yin, Yuanfei Fu, Di Zhang, Weijie Lu, Lin Hua, and Lai-Chang Zhang 8 August 2018	FSP was successfully employed to produce gradient multi-phase structured Ti-6Al-4V/Ag nanocomposite surface layer. Microstructural evolution of amorphous/nanocrystalline/nano-twin in the surface layer was characterized by TEM in detail.	The microstructure was observed by transmission electron microscopy (TEM) and high-resolution TEM (HRTEM), equipped with EDS using a JEM 2100 microscope operated at 200 kV.	During the deformation processes, more dislocations were stopped and tangled, and the potential deformation bands were formed.

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26	Microstructure and sliding wear characterization of Cu/TiB2 supermatrix composition fabricated via FSP.	I. Dinah ran, S.Saravanakumar, K.kalaiselvan, S.Gopalakrishnan3 September 2017	The poor wear performance of cupro is improved by reinforcing hard ceramic particles. The fabrication of Cu/TiB2 (0,6,12,18A vol%) copper composites using FSP.TiB2 particles were initially packed together into a machined groove and were subjected to FSP under a constant set of process parameters.	The microstructure was observed using scanning and transmission electron microscopy. The wear behavior was examined using a pin-on-disc apparatus. The microhardness was found to be 64 HV at0 vol.% and 128 HV at 18 vol.%.	The grains of Cu/18 vol.% TiB2CMC showed a finer structure compared to the coarser grain structure of pure cupro. The grain refinement was attributed to dynamic recrystallization and pinning effect of TiB2particles. The wear rate of Cu/TiB2CMCs decreased with an increased volume fraction of TiB2particles.
27	Cavitation erosion of NiAl-bronze layers generated by friction surfacing	Stefanie Hanke,∗, Alfons Fischer, Matthias Beyer, Jorge dos Santos 13 June 2011	For this investigation coating layers of NiAl-bronze were deposited by friction surfacing on self-mating substrates, followed by microstructural characterization. cavitation tests were performed in order to investigate wear resistance. Cavitation erosion mechanisms were analyzed by means of optical and electron microscopy.	The sample is fastened to a the holder which is lowered into a container filled with the medium for cavitation. In the present study, distilled water was used and the sample was submerged 12–15 mm below the water surface.	Single layer coatings generated by friction surfacing of NiAlbronze on similar substrate material exhibit a fine-grained, homogeneous microstructure. The improved wear behavior of the coatings seems to be due to two differences in wear mechanisms(ductile behavior and increasing influence of corrosion on wear)
28	Wear characteristics of Al–Cr–O surface nanocomposite layer fabricated on the Al6061 plate by FSP	S.R. Anvari n, F.Karimzadeh, M.H.Enayati 25 April 2013	Al–Cr–O hybrid nanocomposites have been fabricated in-situ on the surface of the Al6061 plate by FSP.A new procedure was introduced for applying the reinforcement particles, in which Cr2O3 powder was applied on the Al6061 plate by atmosphere plasma spray and then the FSP was performed on the plate.	X-ray diffraction (XRD) was used to analyze the phases present in the specimens. Scanning electron microscope (SEM) and transmission electron microscope (TEM) were used to study microstructures. The sliding wear behavior of the specimens was evaluated by using a reciprocating wear tester	FSP reduced the wear resistance of Al6061-T6 without reinforcement due to the loss of hardening precipitates during the process. Dispersion of reinforcement particles as hard ceramic phase in Al improves the wear resistance.
29	Friction and wear performance of cupro–graphite surface composites fabricated by FSP.	H. Sarmadi n, A.H.Kokabi, S.M.SeyedReihani 30 April 2013	In this study, FSP was used to produce cupro–graphite surface composites. Graphite particles were added into grooves so that the grooves were completely filled. Five tools with different pin profile were employed in order to achieve a comprehensive dispersion. Results show that the tool with triangular pin gives rise to a better dispersion of graphite particles.	the metallographic investigation was carried out using both OM, SEM. EDS analysis was used for both pin and disk to determine wear mechanism. Vickers microhardness of specimens was also measured using 50g load for 10s applying on a cross-section of each specimen.	Wear loss of the composites was also decreased with increase in graphite content. Using a tool with triangular pin leads to better distribution of particle rather than other tools which are because of the flow pattern of materials against this tool. The area of the composite produced with this tool is larger in comparison with composites produced by other tools.

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30	Microstructural evolution and mechanical properties of a friction-stir processed Ti hydroxyapatite (HA) nanocomposite	R. Rahmati, F. Khodabakhshi 19 August 2018	A new metal matrix nanocomposite with enhanced capability for biomedical applications were fabricated by incorporation of nano-sized hydroxyapatite (HA) particles within the titanium substrate using multi-pass FSP. Rectangular groove with a width of 1.2 mm and a depth of 3.5 mm was machined along the length of the workpiece and it was fully filled with the HA nanoparticles.	Vickers micro-hardness measurements were conducted from annealed titanium substrate in five random points. The fracture surfaces of the broken materials were studied under FE-SEM microscope equipped with an EDS analyzer.	Introducing HA nanoparticles and FSP modification leads to a considerable grain structural refinement according to the operative dynamic restoration. Completely ductile and combined ductile-brittle fracture behaviors were found for the pure-Ti and Ti/n-HA specimens after FSP modification,

3. Friction stir processing

Friction stir processing (FSP) has evolved from the basic principles of friction stir welding (FSW) and emerged as a promising tool to alter the surface microstructure of metallic sheets and plates. During FSP, a non-consumable tool comprising a shoulder and pin rubs against the work material and produces enormous frictional heat. The heat, combined with deformation by the stirring action of tool pin and pressure due to tool shoulder, produces a defect-free, recrystallized, fine-grained microstructure and it is an effective method for producing a surface composite, modifying the microstructure of materials, and synthesizing the composite and intermetallic compound.

As shown in Fig. 1, FSP has demonstrated its potential in the fabrication of all variants of surface composites with little or no interfacial reaction with the reinforcement. The mechanism of FSP which has been divided into four zones as defined the first is affected material or parent metal: This is material remote from the weld that has not been deformed and that, although it may have experienced a thermal cycle from the weld, is not affected by the heat in terms of micro - structure or mechanical properties. Second is the Heat-affected zone: In this region, which lies closer to the weld-center, the material has experienced a thermal cycle that has modified the microstructure and/or the mechanical properties. However, there is no plastic deformation occurring in this area. A third region is Thermo mechanically affected zone (TMAZ): In this region, the FSW tool has plastically deformed the material, and the heat from the process will also have exerted some influence on the material. In the case of aluminum, it is possible to obtain significant plastic strain without recrystallization in this region, and there is generally a distinct boundary between the recrystallized zone (weld nugget) and the deformed zones of the TMAZ. Lastly the Fourth region is defined as Weld nugget: The fully recrystallized area, sometimes called the stir zone, refers to the zone previously occupied by the tool pin. The term stir zone is commonly used in friction stir processing, where large volumes of material are processed [8]-[10].

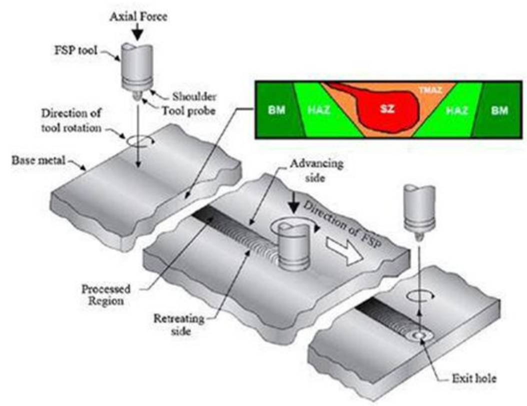

Fig. 1. Process and the mechanism of Friction Stir Processing

Conventional techniques for fabricating surface composites involves liquid phase processing at high temperatures such as laser melt treatment and plasma spraying, which may lead to the deterioration of composite properties due to an interfacial reaction between reinforcement and the metal matrix. Moreover, precise control of processing parameters is required to obtain the desired microstructure in the surface layer after solidification.

4. Materials and methods

Commercially available CuNi sheet was used as the matrix. The optical and Field Emission Scanning Electron Microscope (FESEM) micrographs of the candidate material CuNi alloy are used for the analysis. Based on optical emission spectroscopy analysis, nickel (11.43 wt.%) as the major alloying element together with 1.20 wt. % Fe, 0.79 wt. % Mn, 0.03 wt. % Zn and the balance cupro. For charging ceramic particles, a square groove of length 100 mm, depth 2.5mm with the varying width

(0.35mm, 0.7mm, 1.05mm, and 1.4mm) was made at the center of each plate employing wire-EDM. The grooves were filled with ZrC of particle size ~5 µm in order to produce surface composites. Two-stage friction stir processing of the plates was carried over employing a primitive made FSW. In the Primarily stage, tungsten carbide (WCK10 series) pin-less tool was used to close the groove so as to avoid spilling of ceramic particles during FSP. In the subsequent stage, an FSP tool made of the same WC material with shoulder ø25 mm and taper pin profile with pin tip ø3 mm, pin root ø5 mm to a span of 3 mm, was used.

5. Identification of process parameters

In Surface composite developed through FSP is influenced by many parameters that can be categorized mainly into two, primary and secondary FSP parameters. Former parameters includes rotational speed of tool (N), traverse speed (S), and groove width (W), [14], [15] while the latter comprises type of ceramic particulates (C), axial force, tool tilt angle, shoulder diameter, shoulder profile, pin diameter, etc. are also important secondary parameters that affect the flow of material and generation of heat etc. [16]. Developing a design of experiment including all the primary and secondary parameters will be a complex concern. In order to avoid this complexity, certain unavoidable parameters of FSP including N, S, C, and W were identified and the effect of the same was produced through this research [15].

6. Conclusion

The above research article indicates that there are numerous methods available for the surface hardening, among that FSP has a crucial advantage over the other techniques. Tool rotational speed, tool traverse speed, groove width, and ceramic particulates type significantly affect the microhardness and wear rate of CuNi. The mechanism involved in microhardness, wear resistance and surface area increment is due to strain hardening and particle distribution.FSP area was witnessed to be maximum at minimum groove width, lower traverse speed, and higher tool rotational speed. Thus this attempt made will further enhance the usage of CuNi alloy for mechanical application.

References

[1] Ma, A.L., Jiang, S.L., Zheng, Y.G., Ke, W. Corrosion product film formed on the 90/10cupro–nickel tube in natural seawater composition/structure and formation mechanism. *Corrosion Science* 2015, 91, 245–261.
[2] Ramesh, C.S., Ahmed, R.N., Mujeebu, M.A., Abdullah, M.Z. Development and performance analysis of novel cast cupro–SiC–Gr hybrid composites. *Materials and Design* 2009, 30, 1957–1965.
[3] Rajkumar, K., Aravindan, S. Tribological performance of microwave sintered copper–TiC–graphite hybrid composites. *Tribology International* 2011, 144, 347–358.
[4] Attia, A.N. Surface metal matrix composites. *Materials and Design* 2001, 22, 451–457.
[5] Romankova, S., Hayasaka, Y., Shchetinin, I.V., Yoona, J.M., Komarov, S. "Fabrication of Cu–SiC surface composite under ball collisions. *Applied Surface Science* 2011, 257, 5032–5036.
[6] Zhuang, J., Liu, Y.B., Cao, Z.Y., Li, Y.Y. The Influence of Technological Process on Dry Sliding Wear Behaviour of Titanium Carbide Reinforcement CuproMatrix Composites. *Materials Transactions* 2010, 51, 2311-2317.
[7] Mishra, R.S., Ma, Z.Y., Charity, I. Friction stir processing: a novel technique for fabrication of surface composite. *Materials Science and Engineering* 2003, A341, 307– 310.
[8] Arora, H.S., Singh, H., Dhindaw, B.K. Composite fabrication using friction stir processing-a review. *International Journal of Manufacturing Technology* 2012, 61, 1043–1055.
[9] Rejil, C.M.; Dinaharan, I.; Vijay, S.J. and Murugan, N. Microstructure and sliding wear behavior of AA6360/ (TiC + B4C) hybrid surface composite layer synthesized by friction stir processing on an aluminum substrate. *Materials Science and Engineering* 2012,552, 336–344.
[10] Dolatkhah, A., Golbabaei, P., Besharati Givi, M.K., Molaiekiya, F. Investigating effects of process parameters on microstructural and mechanical properties of Al5052/SiC metal matrix composite fabricated via friction stir processing. *Materials and Design* 2012, 37, 458–464.
[11] Mishra, R.S., Ma, Z.Y. Friction stir welding and processing. *Materials Science and* Engineering 2005, 50, 1-78.
[12] Buchheit, R.G., Grant, R.P., Hlava, P.F., McKenzie, B. and Zender, G.L., 1997. Local dissolution phenomena associated with S phase (Al2CuMg) particles in aluminum alloy 2024-T3. *Journal of the Electrochemical Society*, *144*(8), pp. 2621-2628.
[13] Bierwagen, G.P., He, L., Li, J., Ellingson, L. and Tallman, D.E., 2000. Studies of a new accelerated evaluation method for coating corrosion resistance—thermal cycling testing. *Progress in organic coatings*, *39*(1), pp. 67-78.
[14] Sathiskumar, R., Murugan, N., Dinaharan, I., Vijay, S.J. Prediction of mechanical and wear properties of cupro surface composites fabricated using friction stir processing *Materials and Design* 2014, 55, 224-234.
[15] Dinaharan, I., Murugan, N., Siva Parameswaran. Developing an empirical relationship to predict the influence of process parameters on the tensile strength of friction stir welded AA6061/0-10 wt% ZrB2 Insitu composite. *Transactions of the Indian Institute of Metals* 2012, 65(2), 159-170.
[16] Ramachandran KK, Murugan N, Shashikumar S. An assessment on friction stir welding of high melting temperature materials. *Applied Mechanics and Materials* 2014,592, 43-47.
[17] F. Khodabakhshi, B. Marzbanrad, L.H. Shah, H. Jahed, A.P. Gerlich, Friction-stir processing of a cold sprayed AA7075 coating layer on the AZ31B substrate: Structural homogeneity, microstructures, and hardness.
[18] M.A. García-Bernal, R.S. Mishra, R. Verma, and D.Hernández-Silva, Influence of friction stir processing tool design on microstructure and superplastic behavior of Al-Mg alloys, *Materials Science & Engineering.*
[19] Nithin Kumar pal, R.P. Pandey, Fabrication of AA7005/TiB2-B4C surface composite by FSP.
[20] Z.Y. Zhang a, R. Yang b, Y. Li a, G. Chen a, Y.T. Zhao a, M.P. Liu Microstructural evolution and mechanical properties of friction stir processed ZrB2/6061Al nanocomposites, School of Material Science and Engineering, Jiangsu University, Zhenjiang, 212013.
[21] Z.W. Zhang, Z.Y. Liu, B.L. Xiao, D.R. Ni, Z.Y. Ma, High efficiency dispersal and strengthening of graphene-reinforced aluminum alloy composites fabricated by powder metallurgy combined with friction stir processing.
[22] Ali Hosseinzadeh, Guney Guven Yapici, High-Temperature Characteristics of Al2024/SiC Metal Matrix Composite fabricated by Friction Stir Processing, *Materials Science & Engineering.*
[23] R. Rahmati and F. Khodabakhshi, Microstructural evolution and mechanical properties of a friction-stir processed Ti-hydroxyapatite (HA) nanocomposite, *Journal of the Mechanical Behavior of Biomedical Materials.*
[24] Lakshminarayanan AK, Balasubramanian V. Comparison of RSM with ANN in predicting the tensile strength of friction stir welded AA7039 aluminum alloy joints. *Transaction of Nonferrous Metal Society China 2009*, 19, 9–18.
[25] Elangovan, K., Balasubramanian, V., Babu, S. Predicting tensile strength of friction stir welding AA 6061 aluminum alloy joints by a mathematical model. *Materials and Design* 2009, 30, 188-93.
[26] Dinaharan, I., Murugan, N., Thangarasu, A. Development of empirical relationships for prediction of mechanical and wear properties of AA6082 aluminum matrix composites produced using friction stir processing.

Engineering Science and Technology, an International Journal 2016, 19, 1132-44.
[27] Sharma, V., Prakash, U., Kumar, B.V.M. Surface composites by friction stir processing: a review. *Journal of Materials Processing Technology* 2015, 224, 117–134.
[28] Moghaddas, M.A., Bozorg, S.F.K. Effects of thermal conditions on microstructure in nanocomposite of Al/Si3N4 produced by friction stir processing. *Materials Science and Engineering A* 2013, 559, 187–193.
[29] Titus Thankachan, Soorya Prakash, K., Kavimani, V. Investigation on the effect of friction stir processing on Cu-BN surface composites. Materials and Manufacturing Process 2017, 1532-2475.
[30] Bo Li, Yifu Shen, Luo Lei, Weiye Hu. Fabrication and evaluation of Ti3Alp/Ti-6Al-4V surface layer via additive friction stir processing, Materials and Manufacturing Process 2014, 29(4), 412-417.
[31] Mandal, A., Chakraborty, M., Murty, B.S. Effect of TiB2 particles on sliding wear behavior of Al–4Cu alloy. *Wear* 2007**,** 262, 160–166.
[32] Mohsen Barmouz, Mohammad Kazem Besharati. On the role of processing parameters in producing Cu/SiC MMC via. FSP. *Materials Characterization* 2011, 62(1), 108-117.
[33] Akramifard, H.R., Shamanian, M., Sabbaghian, M., Esmailzadeh, M. Microstructure and mechanical properties of Cu/SiC metal matrix composite fabricated via friction stir processing. *Materials and Design* 2014, 54, 838-844.
[34] Hashim, J., Looney, L., Hashmi, M.S.J. Metal matrix composites: production by the stir casting method. Journal of *Materials Processing Technology* 1999, 92–93, 1–7.