A Review of Friction Stir Processing (FSP) on Stir Cast Aluminum Based Composites

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Abstract

Extensive scientific study has been conducted to improve materials' properties in engineering applications, leading to alternative material manufacturing methods. In the last three decades, aluminium and its alloys have become the most preferred matrix materials for manufacturing MMCs. When deployed, these composites offer lightweight, ease of manufacturing, and corrosion resistance. Several fabrication procedures were established to synthesize aluminium alloys with reinforcement to manufacture; casting can manufacture Aluminium Metal Composite (AMC) at a low cost. On the other hand, cast composites exhibit segregation, aggression, porosity, and polygonal-shaped particles on the surface, prompting some secondary operations to correct these flaws. The inherent process characteristics make FSP the most widely used secondary manufacturing process for surface modification of components. In principle, FSP causes total particle rearrangement and homogenous distribution because of a material flow in 3D and rotating tool stirring action. This review article presents a comprehensive study on the influence of reinforcement particles Al3Ni, Al2Cu, Al3Zr, Al3Fe, Al2O3, SiC, and CB on the microstructural and mechanical behavior of component components of aluminium-based alloys. Aluminium Metal Matrix Composite (AMMC) fabricated with FSP. This literature review concludes a more excellent range of plastic deformation, and the pinning effect of reinforcing material particles causes significant grain size decrements. After FSP, the dislocations density increased substantially; ductility and ultimate strength were improved due to the microstructural alterations.

Keywords: *Mechanical Properties, Stir Casting, Aluminium Matrix Composite, Microstructure, Friction Stir Processing.*

1. Introduction

The widely used aluminium and its alloys are necessary for various construction solutions. Properties including specific strength, lightweight, high ductility, and good corrosion resistance are responsible for its wide acceptability in the automobile, light rail, shipbuilding, aerospace, and other industries [1]. However, industrial people prefer to use steel alloys over aluminum alloys in various engineering applications [2][3]. But Aluminium alloy has some poor surface properties like wear resistance in high load application limits the use of Al alloy in structural application. Moreover, due to the 'thin-ice effect,' thin hard coatings on Al alloys do not last in high-loading situations [4]. Therefore, many researchers proposed various methods to improve the mechanical behavior of bulk material. For more than thirty years, Metal Matrix Composites has been the most suitable solution to meet the demands of industries in comparison to other fabrication techniques. Metal matrix composites are constantly replacing traditional building materials. They are used in the automotive, construction, transportation, and shipping industries. Their excellent combination of higher modulus, lightweight, high rigidity, and higher wear resistance receives more attention. With the help of introducing participating reinforcement, we can customize the MMC properties as per our requirement [5]. MMC combines a matrix made of ductile metals or alloys and then reinforced by other metals, non-metals, or organic compounds [6]. MMC can form a rigid reinforcing material included in the matrix material to improve qualities, including elastic strength, specificity war, and corrosion resistance.

Al, Mg, Cu, Fe, and Ti are the most common and available matrix material for MMC; Researcher has proven and found so many applications on Al and Mg, which is widely used in industries. Magnesium-based compounds have received attention compared to bulk alloys due to their impressive mechanical characteristics. However, there are several drawbacks to using magnesium in automotive. The leading cause is the lower ductility and strength. In addition, magnesium is highly reactive at high temperatures. However, this can be forbidden by the surface coating or its natural oxide[6]. To prevent oxidation, an inert atmosphere must be maintained while manufacturing magnesium-based MMC. One of the main disadvantages of iron as a matrix compared to composite materials is its brittleness and lower impact strength. For that reason, composite materials based on steel and metal matrix only have colossal potential designed for wear-resistant applications [7]. Copper is used mainly as a matrix material in MMC, where conductivity (thermal and electrical) plays an important task. Copper in pure form cannot be used for many industrial applications on a substrate due to its low resistance[8]. Compared with the other matrix materials, aluminium as an alloying element is commonly used to manufacture MMC. Different eye-catching properties of aluminum include lightweight, economic feasibility, ease of processing using various technologies, strength-weight ratio, and resistance in opposition to corrosion [9].

An MMC’s performance mainly depends on the dealing out method; thus, the choice of manufacturing method plays a vital role in meeting industrial requirements and ensuring functional characteristics[10]. Generally speaking, the disadvantage of AMMC manufacturing is the high production cost, reinforcing materials, distribution of reinforcing materials in the matrix are heterogeneous. Therefore, an economical method of manufacturing composite materials is essential to expand its use [11]. Fabrication processes for bulk AMMC’s include casting of composite, infiltration, direct melt oxidation, powder metallurgy, and stir casting [12]. Narendra

Kumar et al. [13] outlines the possibilities of synthesizing titanium diboride-enhanced AMC using various techniques. Vertical centrifugal and gravity die casting processes were used to produce aluminum LM30. The transition of graphite gradually and the outer region of microstructure was observed with primary silicon [14].

The review articles on MMC available in open literature reveal that no comprehensive review is public, especially on the AMMC fabricated with the stir casting process. Kamyar et al. [15] have published many review papers in MMCs since 2000, and most of them are on production techniques. Torralba et al. [16] focused on the powder metallurgy method for MMC production. Magnesium-based MMC is the center of attention of Ye and Liu[17], with only a single part dedicated to the manufacturing process. MMC properties required for several applications are discussed by Miracle[18] with production processes. Likewise, Qu et al. [19] also targeted MMCs application in thermal management. Ye et al. [20] presented an exhaustive review on using the injection moulding method in MMCs manufacturing. Silvestre [21] and Bakshi et al. [22] have reviewed carbon nano-tube reinforced MMCswith and do not face a large spectrum of reinforcement debris in addition to the manufacturing processes.

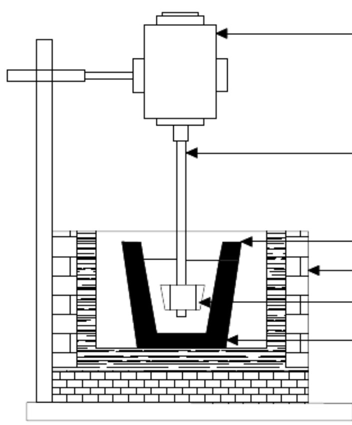

Fig. 1 Stir casting process to fabricate MMC

The studies reveal that approximately 67% of MMCs are fabricated by stir casting methods [18], so this method requires more care to fabricate the composite. Various parameters that play a vital role in these techniques are furnace design, reinforcement material, stirrer speed, and furnace temperature. Aschematic diagram of the stir casting process is shown in **Fig 1**. Overall, research progress has been going on in the ground of improvement of stir casting for MMCs. Therefore, this review paper aims to focus on stir casting AMC. The liquid form of the metal matrix is mixed with the ceramic or fiber particle in the stir casting process; while selecting the stir casting process, extra care is required for homogeneous particles, good quality bonding connecting matrix and reinforcement, reducing permeability percentage, and avoiding chemical reaction with the environment.

Casati and Vedani [23] focused on enhanced MMC nano particles, while Kara et al. presented the mechanical properties and tribological behavior of stir-casted Aluminum-based MMC [11].

The overview clearly shows that so far, no reviewer has presented a review that focused on production processes using the stir casting process. Limited numbers of papers focus on MMC produced with the stir casting process. The stir casting route and its problems were discussed by Kumar and Menghani [24], but the design considerations and suggestions for stir casting were ignored. Although Suthar and Patel addressed the processing of AMMC stir casting[25], they also discussed the processing and application of AMMC. Kumar et al. [26] summarize the manufacturing and performance of MMC made by the stir casting method. To produce the mechanical properties in the compound, Shabani, and Mazahery[27] introduced a new method named as semi-solid agitation process in stir casting.7075 aluminum composite was made from nano-silicon carbide (SiC) reinforced materials in various weight ratios by stir casting. In the study done by Suresh et al., the nano-composite wear rate was decreased [28].

1.1 Defects in AMC fabricated via stir casting method

Composite made with casting method is cheaper than various other processing techniques. The production cost is about one-third compared to other methods. But additional care is to be taken while fabricating composite by casting processes. Stirring time, stirring speed, preheating of reinforcement, and base metal is the most affecting parameter to proper synthesis composite via this method [29]. The major problems faced include; uneven(Heterogeneous) distribution of reinforcement material in the matrix material. Also, cast MMC has some porosity, and reinforcement material has some chemical reactions with matrix material [30]. The stir casting process successfully produced composite materials with aluminum matrix and fly ash as reinforcement elements [31]. It demonstrates that adding a certain weight percent of fly ash to AMC improves its mechanical characteristics. They are using eight weight percentages of flyash impacts elongation and density measurement. SEM image reveals the allocation of flyash particles in AMC. In addition, some pores were found in the sample cross-section, and AMC products' mechanical properties were reduced. Density measurement confirmed that the AMC sample with the highest density value has the most excellent toughness and tensile strength.

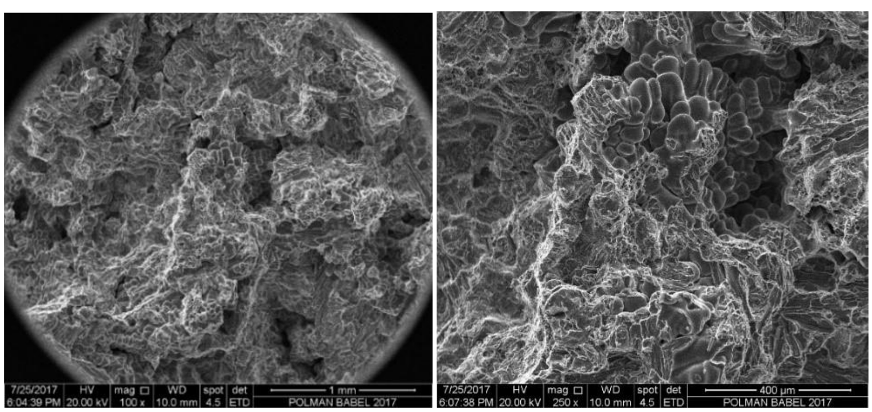

Fig. 2 SEM images analysis of AMC fabricated with flyash [31]

The ductility of the composite base surface component is reduced with the addition of fly ash. A P Singh et al. [32] has observed porosity in their specimen. The authors have selected AA2024 as matrix metal with different wt% of Al_20_3/ZrO_2/Gr reinforcement particle, and a stir casting process was used to make the composite. Percentage change in density and porosity of the reinforced material Al_2O_3/ZrO_2/Gr in HMMC is given in **Table 1**. It shows that the weight percentage of reinforcement material plays a major part in the density of HMMC. With the increase in reinforcement weight, particle percentage density of composite increases gradually. The highest density was observed in the section with 10% wt (Al_20_3/ZrO_2/Gr). The porosity of the sample with four wt% reinforcement (Al_20_3/ZrO_2/Gr) is very high.

Table 1. Porosity and Density value with wt% of Reinforcement

Wt% of Reinforcement	Porosity Level (%)	Theoretical Density(g/cm^3)	Experimental Density(g/cm^3)
3%	1.78 %	2.796	2.746
4%	10.31 %	2.801	2.512
6%	8.17 %	2.812	2.582
10%	4.55 %	2.834	2.705

S. Arunkumar et al. made the composite with the stir casting method using AA7075 with reinforcement particle silicon nitride weight percentages of 4,8, and 12 [33]. Stir casted specimen microstructure image was captured with the help of an optical metallurgical microscope. **Fig 3a and 3b** show the porosity in the sample before and after the heat treatment. Higher porosity was found in especially 8% of Si_3N_4. This study measured porosity using image interpretation software, NDE technique, and X-ray tomography. The paper reported that the creation of porosity is caused due to gas setup during stirring penetrates the air bubbles in the slurry or air envelop to the reinforcement particle, particle surface water vapor, solidification contraction, and particle fraction (by volume) in MMC. They used a heat treatment process to remove the porosity in the composite.

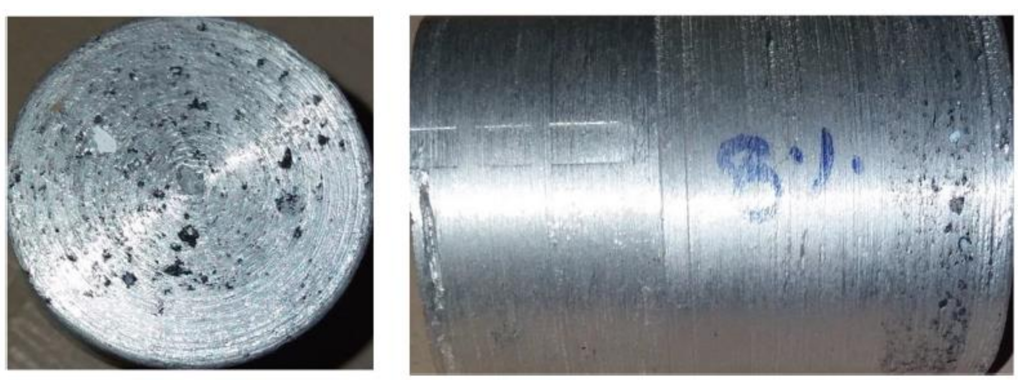

Fig. 3 a. Porosity of stir cast (8% Si3N4 with Al7075) alloy [33]

Fig 3 b. Heat-treated at 550°C specimen microscopic image [33]

1.2. Need of additional process

Surplus structural components were found in the aluminium matrix, excluding grain boundaries, particle aggression, wettability polygonal-shaped particles, and porosity. Mechanical properties decrease with these types of defects and porosity. Void coalescence, reduction in ductility is the effect of the presence of pores in composite material. Controlling some process parameters such as stirring time, temperature, cooling time porosity reduced significantly. Porosity is also reduced employing heat treatment, but there is also a presence of some minor porosity that deteriorates the component's mechanical property. Some additional processing techniques are there to change the microstructure and morphology, which helps to improve the mechanical properties of Cast AMC like rolling, extrusion, forging [34, 35, 36], and equal channel angular processing techniques. The spherical microstructure achieves casting porosity reduction and micro segregation [35]. However, due to the lack of deformation in 3Dand material flow during the process, the total change in distribution and morphology was not likely to improve the tensile properties. FSP as a solid-state technique has a better cutting edge for fairer particle distribution and reinforcement morphology. FSP was used for grain refinement of metal-based material at the surface, and its use to improve the AMCs properties presently.

2. Friction Stir Processing (FSP)

This method was established from technology with similar processes and principles[36][34]. The homogeneous microstructure is obtained by stirring, and material heating forms the plastic deformation.

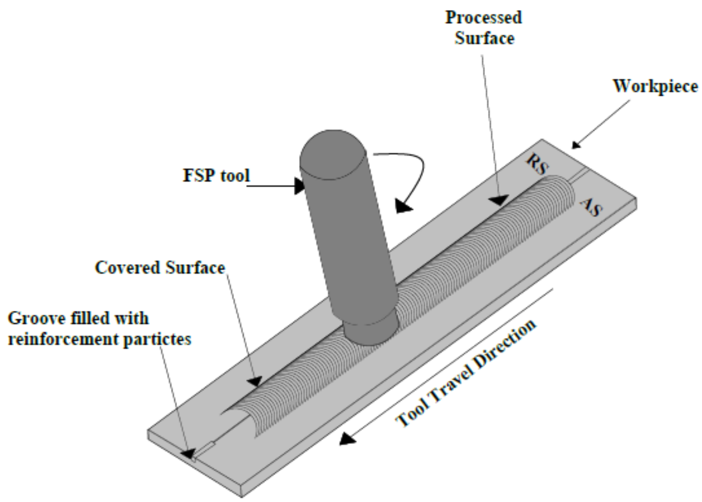

Fig. 4 Strategy of Friction Stir Processing

Fig. 4 illustrates the basic principle of FSP/FSW approaches. A rotating pin (non-consumable type) is used to stir Substrate (base metal). The tool moves in the line of joint of the workpiece, and a considerable amount of heat is generated on the material's surface. This friction heat softens the heat processing zone of workpiece material with a temperature rise. The material undergoes this processing zone, severs plastic deformation with pin rotation and traversing along the joint. Resulting this movement modifies metallic micro-structure and refines the grain homogeneity. To solve the above-discussed material defects in alloys and composite material FSP is widely used nowadays. FSP enhances the micro-structure of the workpiece below the base alloy melting temperature. FSP is used to enhance mechanical properties with locally modifies the microstructure. Compared to other surface modifications of metallic component techniques, FSP achieves more attention. Without a change in size or shape, FSP can improve strength, can give more homogeneous distribution and grain refinement [36]. Mechanical properties and microstructure can be managed by varying the process parameters [37][38]. FSP found many industrial and practical applications in recent decades [39]. FSP technology is used to form equiaxed nanograin and structural homogenization[40][41][42], modify and harden metallic material with compositional subsurface gradient structure [43][44], to form in situ composites [45][46] currently. This review is focused on FSP on Aluminum alloy and AMMC.

2.1 FSP for different Aluminium Alloy

The experimental research presents that a single-pass Friction Stir Process at low tool speed can decrease aluminum the grain size of aluminum alloy by an average of 85-95%. **Fig. 5** shows aluminum alloy's typical macro and microstructures before and after FSP [39]. Zhao et al. [40] reviewed the result data for grain structure and strength of aluminum alloy before and after the FSP process. The FSP Pass, tool rotation rate, and tool transverse rate were the selection parameters for aluminum alloy grade. Refinement of the microstructure, reduction of porosity of primary particles of silicon from 188μm to1.6μm and α Al grain size from a range of 0.4μm to 0.51 μm also increment in hardness was measured with an increment in several passes of A356 aluminum alloy. They observed finer microstructure after each pass of FSP and showed no noticeable refinement of subgrains after six passes. The comparative study was observed in Table 2 Ref. [39]. The grain size of 5µm to 8 µm and 8.5µm to 9.7µm was observed after one pass and two passes of FSP as tool rotation speed between 300-1200 rpm [40]. In some cases, with increasing grain refinement, mechanical properties also deteriorate as compared to unprocessed FSP zone. This is because the substrate contains high-density needle-like precipitates, which are reduced after FSP, or because the precipitates are dissolved due to high-temperature stress during processing. The mixed zone is why its mechanical properties are lower than the base material [41]. Ramesh et al. [47] studied intermittent and continuous one-stage and twelfth-stage FSP on 5086 aluminum alloy at a fixed speed of 1025 rpm, but the variable lateral speed varying from 30mm/min to 150 mm/min showed a corresponding decrease in grain size. At a lateral speed of 30 mm/min, single-stage and multi-stage FSP can prove to achieve the best alloy structure and performance. The studies also show, how with the further increment of the lateral velocity, ductility increases, strength of 5086 alloy decreases while the average grain size increases and then decreases [47].

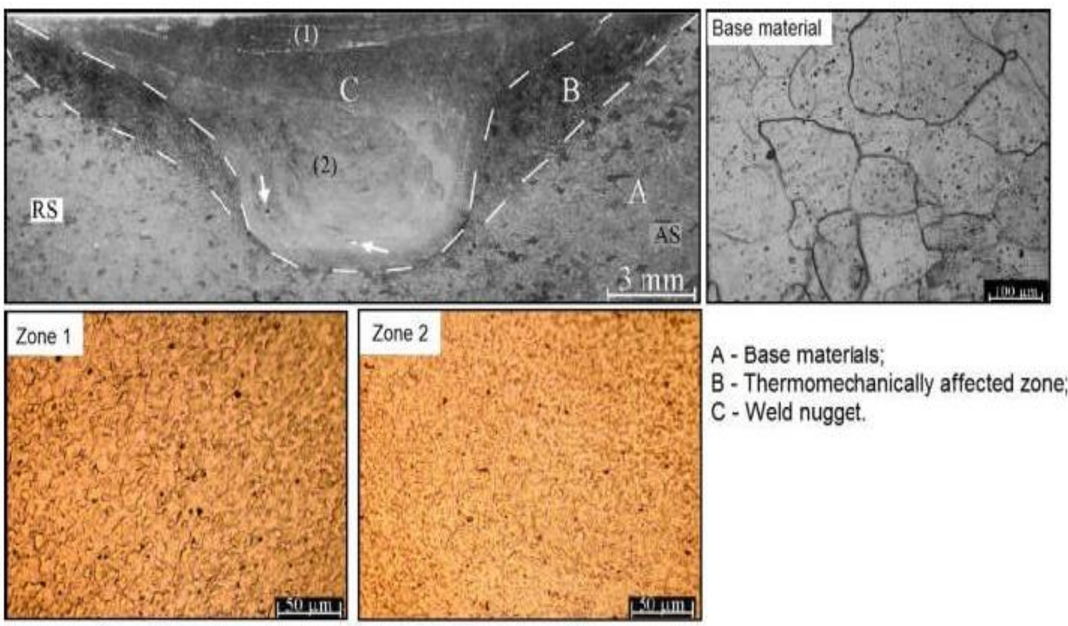

Fig. 5 FSPed 6063 aluminium alloy Macro and microstructure of single-pass[39]

Table 2. FSP on aluminium alloy experimental data

Material	Transverse Rate of Tool mm/min	Rotation Rate of Tool rpm	Passes	Average Grain Size Parent alloy/after FSP	Effect on Mechanical Properties	Reference Number
A356	16	350	Single	–/0.74	Microhardness (HV): 68	[48]
			Two	–/0.58	Microhardness (HV): 92	
			Three	–/0.45	Microhardness (HV): 113	
Al–12Si	28	1400	Single	25/–	Microhardness %: 20.9 (+ive)	[49]
					Ultimate Tensile Strength: 15.1% (+ive)	
					Elongation: 3.7 times (+ive)	
Al5052	80	1120	Single	243/16.5	Microhardness %: 13.3 (+ive)	[50]
	127	490	Single	–/10.7	Microhardness (HV):42.6	
					Ultimate Tensile Strength: 135.3 MPa	
					Elongation %: 34.4	
AA5005–H34		970		–/18.5	Microhardness (HV): 38.9	[41]
					Ultimate Tensile Strength: 118.7 MPa	
					Elongation %: 37.3	
		1200		–/20.4	Microhardness (HV): 37.9	
					Ultimate Tensile Strength: 119.3 MPa	
					Elongation %: 41.4	
6063		300	Single	134/5.3	Ultimate Tensile Strength %: 6 (-ive)	[40]
					Elongation %: 42 (-ive)	
			Two	134/8.6	Ultimate Tensile Strength %: 21 (-	

					ive)	
					Elongation %: 40 (-ive)	
		500	Single	134/5.5	Ultimate Tensile Strength: no change	
					Elongation %: 28 (-ive)	
			Two	134/9.6	Ultimate Tensile Strength %: 10 (-ive)	
					Elongation %: 29 (-ive)	
		700	Single	134/7.5	Ultimate Tensile Strength %: 15 (+ive)	
					Elongation %: 36 (-ive)	
			Two	134/9.7	Ultimate Tensile Strength %: 5 (+ive)	
					Elongation %: 36 (-ive)	
		100	Single	134/8	-	
		1200	Single	134/7.8	-	
5086	30	1025	Single	48/7	Microhardness %: 8.6 (+ive)	[47]
					Ultimate Tensile Strength %: 3.8 (+ive)	
					Elongation %: 30.7 (+ive)	
	80			48/10.5	Microhardness %: 8.6 (+ive)	
					Ultimate Tensile Strength %: 9.6 (+ive)	
					Elongation %: 23 (+ive)	
	150			48/3.8	Microhardness %: 10 (+ive)	
					Ultimate Tensile Strength %: 1.9 (+ive)	
AA1050	20	1600	Single	42.85/10.58	Microhardness %: 47.6 (+ive)	[51]
					Coefficient of Friction %: 13.8 (-ive)	

2.2 AMMC Fabricated with FSP

An average grain size (178 µm) of AA7075 was improved and detected to 8 µm, using the tool's triangular shape and stirring action during FSP. Essam B. Moustafa et al. [54] observed nanocomposite was almost free from voids with the uniformly distributed reinforcement particles. Gagandeep Singh Raheja et al. [52] studied the microstructure of the AA5086 base and observed the morphology of the plane. After FSP with a surface composite of Gr-SiC reinforcement, the reinforcement was uniformly distributed in Al Matrix. FSP with square pin geometry tool refine the average grain size by 25 µm to 7.5 µm. Farshid Karpasand et al. [53] examined that increasing reinforcement particles reduces the grain size of Al7075. 250µm grain size of the matrix was reduced to 7 µm by adding a high volumetric fraction of B_4C reinforcement in one stage powder added sample. FSP fabricated defect-free Al7075-B_4C surface composite. Hamidreza Eftekharinia et al. [54] revealed that HAZ, TMAZ, and SZ have different grain structures after FSP of aluminum 6061-T6. Pin geometry affects the microstructure of the FSP specimen, but it was also the result of SiC particle in the component. Square and triangular pin geometry achieved the stir zone's 3.14 and 4.29 µm grain refinement. More refine microstructure was also observed with an increase in FSP pass number. Aluminum and aluminum nitride powder with different weight faction mixed and packed on a surface groove of aluminum alloy (AA6016) to make a surface composite with FSP. FSP reduces the grain size, and a noticeable improvement in microstructure and microhardness is accomplished [55]. SiC particle size of 45µm - 50µm reinforcement added into AA6082 with multi-pass FSP. The author reported different microstructure evolution in the processed zone with increasing passes. A more refined microstructure is observed with a stirring effect and plastic deformation particle in each pass. The average grain size 141 µm of AA6082 was converted to approximately 4 µm after three-pass of FSP, and homogeneous distribution of particle was observed as shown in **Fig. 6** [56]. Al-Al_2O_3-CNTs Composite was created using holes strategy using FSP as a novel approach [57]. The portion underneath the FSP zone having an average grain size varying from 3 µm to 7 µm was observed compared to the base material having an average grain size of 66-73 µm. **Table 3** Shows grain size refinement of composite material after adding the reinforcement in bulk Al alloy via a different strategy.

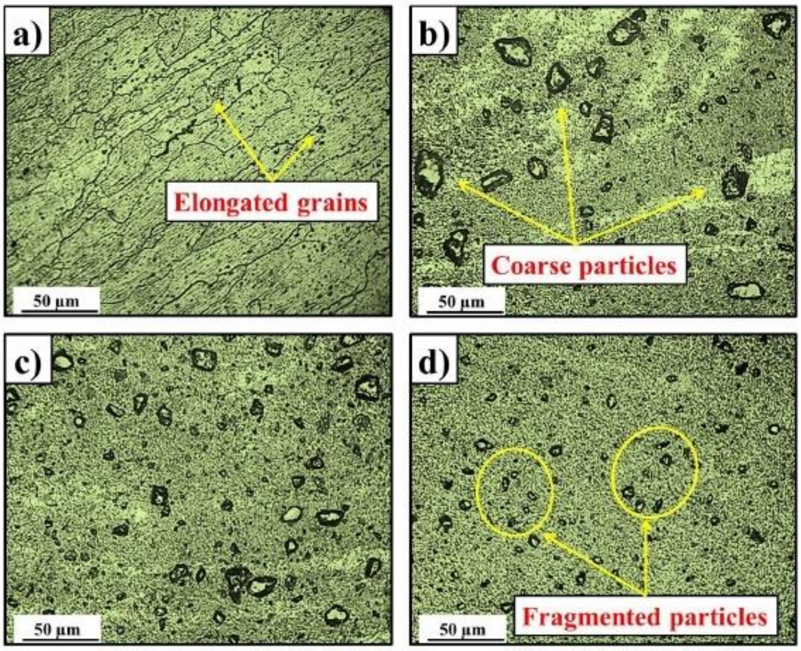

Fig. 6 AA6082 and AA6082/SiC$_p$ composite at single, double and three times pass)[56]

Table 3. Effect on the grain size of the aluminium alloy after FSP

Workpiece Material	Reinforcement Material	Strategy		Microstructure refinement (reduction)	References
		Groove (Width×Depth) mm	Hole (Width×Depth×Spacing)		
AA7075	SiC (7%) and BN (5%) nanopowders	3.0×-	-	178 µm to 8 µm	[58]
Al5086	Nano Graphene (Gr) 5% and Silicon Carbide 20%	-	Holes with powder Particles	25 µmto 7 µm	[52]
Al7075	B_4C	1.0 to 2.0×3.0	-	250 µm to 7 µm	[53]
AA606-T6	SiC	0.7×2	-	3.41 µmand 4.29 µm	[54]
AA6016	Al_2O_3, AlN variable with 25,50,75, 100%	0.5×5.5	-	Noticeable reduction	[55]

AA6082	SiC	2.0×2.4	-	141 μm to 14 -30 μm	[56]
AA6061	multi-walled (CNTs)& Al_2O_3 320nm	-	2.0×2.0×4.0	Grain refinement observed	[57]

As per the above review and discussion, generally, FSP is used to build the Composite material by adding different reinforcement particles. However, it shows a more refined grain size reduction with this strategy. So, there is scope to enhance the mechanical behavior of bulk composite AMMC with the addition FSP process for adequate grin size and homogeneous particle distribution, reducing the composite defects like porosity, wettability, and heterogeneous distribution microstructure.

3. FSP as an additional process on Aluminum Matrix Composite

There are few studies on the utility of applying FSP to AMC. Different researchers have used foreign particles in hybrid friction stir processing on cast composite AMMC. We have focused on some reinforcement material particles and their consequence microstructure as well as mechanical behavior before and after the FSP process.

Nickel Powder

Al_3Ni (0-15 wt.%) AMCs, i.e., AA6061, were synthesized by adding nickel powder into aluminium at molten form by M. Balakrishnan et al. [59]. The microstructure of molten composites had shown improvement in grains size, aggressiveness, segregation. They reported that FSP causes a complete rearrangement of particles, resulting in uneven material distribution flow through the moving of the rotating tool. Furthermore, FSP eliminates casting defects like porosity through proper sealing and plasticization. In addition, FSP improves the tensile strength of the melt through preferred structural changes. Also, results show that improvement in the ductile property.

Copper Powder

For the initiation of the reaction I. Dinaharan, et al. [60] added copper powder (in a specific quantity)to the molten aluminum alloy. AA6061-T6 Cast composites revealed large polygonal-shaped particles, coarse grains, segregation, and pores in the microstructure. The microstructure of the cast composite was improved with another FSP process, which enhances the tensile strength of the composite. There was total particle rearrangement, and three-dimensional material flows with the homogeneous distribution. Fine-sized Al_2Cu particle is observed with the FSP process, which eliminates casting defects like pores and particle segregation. With the process author reported improvement in tensile strength of cast composite.

Zirconium Powder

M. Balakrishnan, et al. [61] in their study, Al/(0–15 wt.%) Al_3Zr based AMCs were produced when zirconium (in powder form) was added to aluminum in the molten state. Many defects like a coarse grain, segregation of particles, porosity, and polygonal shape were found in the cast component. The microstructure size was enhanced by the applied FSP process and improved tensile strength. They conclude that there was a total rearrangement of particle and homogeneous distribution with 3D material flows and stirring of a tool in the component. Particles of Al_3Zr were broken in fine size due to the mechanical impact in FSP. FSP successfully eliminated typical casting defects like pores. FSP improves the hardness and tensile strength of the cast composite with a decrement in grain size and recrystallization of microstructure. Also, the ductility was improved with post FSP.

Iron Powder

Al/(0-15wt%) Al_3Fe AMCs were synthesized by M. Balakrishnana et al. [62] by adding the iron powder to molten aluminum. They have also found coarse grains, segregation, and pores in cast components.FSP as a secondary process was used to enhance the mechanical properties and improve the microstructure of the composite. The result shows that fine grain refinement and Al_3Fe particle were broken down in fine size due to a more significant plastic strain and the effect of the tool rotation on the sample. However, desirable microstructure changes and the tensile property were achieved with FSP.

Silicon Carbide and Carbon Black

with melting and reinforcing carbon black and SiC particles, AA7075 was prepared by Pratip Roy et al. [63]. FSP then processed the resulting mixture with suitable parameters, and different studies were done to comprehend the outcome of FSP on the sample. The result carried out with optical microscope analysis shows that SiC and CB particles have a large grain refinement. In addition, equiaxed ultra-fine grains are obtained for further processing of specimens by using FSP. HAZ, TMAZ, and stir zone have varying microhardness. Compared with the base alloys AA7075, AA7075/SiC, and AA7075/SiC/CB, an increment in microhardness in the sample was observed. AA7075/SiC/CB tensile strength increased 2.5 times with this novel technique and reported an increment in ductility.

Aluminum Oxide

W. Hoziefa, et al. [64] studied the result of FSP on a nanocomposite of semi-solid cast AA2024-1wt.% Al_2O_3. Cast unreinforced AA2024 alloy plate and FSP for the same alloy microstructure were compared using optical microscopy (OM) along with SEM and EBSD. Before and after, FSP of unreinforced AA2021 alloy and AA2021- Al_2O_3 nanocomposite microstructure and tensile strength were determined. The grain size was reported a reduction from 28 μm to grain size of 18 μm cast condition and from a value of 3.7 μm to 2.7 μm in the FSPed with the addition of 1wt% of Al_2O_3 nano particle. In addition, tensile strength was increased by 71%, and 30%improvement in yield strength compared to the cast matrix component. The collective use of casting and FSP proved to be capable of minimizing casting defects and obtaining nanocomposite materials, characterized by the fair distribution of reinforcement materials, high strength, and ductility.

4. Summary

Generally, AMC is fabricated with stir casting as a convenient and mass production process. But additional care and selection of process parameters play an important role in making defect-free composites like porosity, wettability, segregation, large grain size, and heterogeneous microstructure distribution. Many researchers have reported this defect in cast AMC fabricated through stir casting. To change the surface hardness in addition to the mechanical properties of components, the material must have a uniform microstructure distribution.

- FSP can enhance the microstructure of material with plastic deformation lower the material's melting point. Furthermore, the addition of FSP has proven to be a promising process for treating casting defects related to pores and voids and producing surface nano composites, which is characterized by a good distribution of reinforcing elements with great strength and ductility.
- In the FSP, the matrix grains are significantly refined, and the agglomerated nano particles synthesized in situ are distributed homogeneously. As a result, the average microhardness of the core area of the FSPed composite is estimated to be higher than that of the composite.

Conflict of Interest:

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article.

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