A study on the effect of friction stir processing on the properties of aluminium metal matrix composite

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Abstract: Friction Stir Processing (FSP) is a latest technology which was initially developed by using the principle of Friction Stir Welding. Various researchers have performed processing on different aluminium alloys. Also, fabrication of aluminium metal matrix composites was performed by many researchers using this method. In this study, the status of FSP on aluminium MMCs is discussed. FSP has great influence on the surface microstructure, mechanical, tribological and corrosion properties of aluminium MMC. Also, effects of many input parameters such as rotational speed, translation speed, tilt angle and number of passes are to be observed.

Keywords: Friction stir process, Aluminium alloys, Metal matric composite

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Introduction

In general materials having high strength, high elastic modulus, and better resistance to weariness, creep properties which cannot be achieved by single metal/alloy, so there is a requirement of metal composites embedded with ceramic. These ceramics cannot be widely used because of some limitations such as decrease in toughness and ductility properties due to amalgamation of non-deformable ceramic reinforcement. For different applications, we only need surface properties to be changed and the remaining bulk of material does not get affected. There are many ways to modify the surface and to do the same, friction stir process (FSP) is performed to make surface composites by reinforcing particles of ceramics into the layer of Al alloy [1].

FSP consists of a pin, shoulder and revolving tool. In this process, a pin is inserted in material for microstructural modification. FSP produces heat between the tool and material which results in localized heating, generating a heat affected zone affected by heat and thermo mechanically affected zone (TMAZ) that softens and causes the plastic deformation of the workpiece and this results in change in the microstructure of the material and significant grain refinement. This procedure alters the specimen's surface local structure at micro level to give it the desired qualities. It involves different process parameters such as force applied on workpiece, traveling speed, rotational speed and are used to modify the microstructure to improve the performance and quality of the material. This technique, which is used for microstructural development was developed by Mishra in 2000. The most important areas in FSP are between the TMAZ and stir zone; these zones will define the adhesive properties of the modified area [2].

The main process parameters are:

- Rotational speed

Traveling speed

- Penetration depth of tool
- Alloying material

- Clamping system
- Pin dimensions (length, diameter and shape)

To increase the width of processed, either the large diameter of the pin is used or the sample should be processed by multi-pass FSP. Larger diameter of the pin increases the torque which increases the demand of the energy.

Kumar et al. [3] analysed the vibration and wear resistance of the FSPed hybrid AA7075-B4C by using hyperbolic fuzzy entropy (HFE) and single-valued neutrosophic entropy (NFE) for aluminium composite. They concluded that aluminium composites can be used in different applications such as automobiles, aircraft, and robots because of their light weight, high specific stiffness, and high hardness. Maji et al. [4] studied the effects of various processing speeds on MoS2 and CeO2 microparticles in Al7075 alloy by FSP. They concluded that there is enhanced corrosion resistance and in wear properties of MoS2 and CeO2 reinforced novel hybrid Al7075 matrix composites when successfully produced through FSP and by lowering the speed, a lower friction coefficient was obtained.

Gulati et al. [5] examined the wear properties and microstructural properties of an FS processed Al-7075/SiC aluminium matrix. They used friction stir processing and the surface matrix is processed on Al 7075-T651 alloy. It was observed, as traveling speed, rotating speed and tool angle was increased, the strength of the Al 7075-T651/SiC matrix was increased by 1.65 to 2.15 times in comparison to the original material and also reduction in wear rate was seen in case of processed MMC.

Bharti et al. [6] analyzed the influence of FSP on different aluminium alloys of the 6000 series. They observed that the hardness of aluminium alloy AA6360 was improved from 83 HV to 162 HV, the strength of Al 6082 also raised three times from 85 HV to 295 HV, and the hardness of AA6061 changed from 107 HV to 155 HV. Senthilkumar et al. [7] analyzed the effect of the number of passes in FSP of Al alloy 6082. It was concluded that by increasing the passes having the specific rotational speed, the tunnel void at the stir zone can be reduced due to resolidification. Although deformation temperature can be achieved by changing the rate of motion and hence the tunnel gap can't be reduced.

Chaudhary et al. [8]studied the effects of multiple layer accumulation of grade AA alloy 6061 by a FSPAM process. They concluded that there is improved material flowability by raising the temperature at the deposition zone and the multi-layer deposition was found to be 60% of 6061 Aluminium alloy by the FSPAM process. Nisa et al. [9] analyzed the characterization and formation of 6063 aluminium metal using friction stir processing method. They observed a 60% porosity and temperature and heat treatment timing optimization and the best quality foam via this process. FSP helped in embedding powder mixtures into composites of metals that caused pore formation.

Balakrishnan et al. [10] studied the tensile strength of AA6061/Al3Zr aluminum matrix by using friction stir processing. They concluded that due to the stirring action of the rotating tool, the particles rearranged into a homogeneous arrangement. It removed the casting defects and reduced the size of grain in composites due to excess frictional heat and plastic deformation, which also increases the dislocation density. Ductility improvement is confirmed at the fracture surface. Ma and lai. [11]worked on a AL 5083 alloy having gradient structure and it was fabricated by a FSP combined with ultrasonic vibration and the use of N2 in liquid form. It was concluded that the ultimate tensile and yield strength of the USFSP work piece were 53.3% and 27.5% higher, respectively, when compared to Aluminium 5083 alloy. These results were gained without shortening the length of the alloy because of its structure, which has a high density of derangement of grains and a wider refine-grained layer.

Zainelabdeen et al. [12] analyzed the microstructure analysis, mechanical properties, and corrosion resistance of FSP of 6061 AA. They concluded that there was enhancement in the microhardness of the samples and improvement in corrosion resistance over the base metal.] D. Yadav, R. Bauri [13] studied mechanical characterization composites by fabricating two-layer Aluminum -Zinc alloy composite with the help of sheet lamination technique and multi-pass FSP. They concluded that there is formation of rough Cu rich particles by using nano-sized copper particles in the SZ and there is inadequate flow of material in the SZ by decreasing the temperature too much.

Reddy et al. [14] analyzed the effect of the tool's revolving speed and temperature-dependent on the damping capacity of pure FSPed aluminum. It was observed that by increasing the tool speed, there was a decrease in the dislocation density in the SZ. Mohamadigangaraj et al. [15] examined the effects of influence of heat and cooling on the FSP of an A390-10 wt% silicon carbon composite. They noticed that changes in precipitates and particle size occur following annealing heat treatments that lower the matrix's flow stress. Also, solid solution pre-handling caused the creation of rougher and accumulation of precipitates in the structure.

Wang et al. [16]examined SZ's microstructure and mechanical behavior during the fabrication of the AA2014 aluminium alloy plate by CSA-FSP using liquid carbon dioxide cooling. A finer grain structure was seen in the top area of the stir zone as a result of the liquid CO2's better cooling effectiveness during FSP, and the mechanical properties of the entire S Zone were improved as a result of the treated grains and altered phase particle morphology. Lakshminarayanan and Annamalai [17] studied the process parameters like revolving speed, welding rate on the clad properties of dissimilar magnesium aluminum alloy clad joints.They concluded that low rotating speed and fast welding speed decrease interface bonding, which causes uneven aluminium flow and ineffective material mixing.

Balakrishnan et al. [18] Worked on FSP on Al3Ni intermetallic coarse-grained to strengthen cast aluminium composites like microstructure and tensile properties. FSP caused rearrangement of particles due to rotating tools in stirring and also helped to remove normal casting defects such as plasticization. It also facilitates improvement in dislocation density. Zhang et al. [19]analyzed the effects of various inputs of energy in friction stir processing on aluminum and carbon nanocomposites in their internal structure and mechanical properties. They discovered that these material characteristics are almost analogous to energy inputs. An increase in energy input resulted in a little coarsening of the composite of aluminium grains. With a larger increase in energy inputs, an additional 53% rise in tensile strength was also noted.

Akinlabi et al. [20] performed electrochemical investigations with the help of friction stir processing on aluminum-based composites. It was observed that PKSA yielded the maximum resistance with respect to corrosion with 1075 ohm. It was also observed that PKSA has a minimum rate of corrosion of 0.4357 mm/year. Yang et al. [21] used underwater friction stir processing and incorporation of AlCoCrFeNi alloy matrix to achieve modification on aluminum surface. The mechanical properties were investigated, and it was observed that the microhardness and elastic modulus of the matrix were improved, and the obtained composites also showed a lower coefficient of friction.

Manochehrian et al. [22] analyzed the change in microstructural, mechanical properties of aluminium A356 alloy when subjected to friction stir processing. They observed that by increasing Ti3AlC2 content in composites, a significant increase in tensile strength, less coefficient of friction, and an increase in microhardness up to 7.5 TAC is found.

Chandran et al. [23] examined the impact of FSP of aluminium on process variables including tool depth and tool rotation speed. On a vertical milling machine, experiments were carried out using a specific designed FSP tool, and parameters were examined. They concluded that a tool's 500 rpm rotating speed, 14 mm/min transverse feed, and 3.1 mm cut depth result in metal with a higher degree of hardness. Aval H et al. [24] investigated the characteristics of A390- 10wt.% Silicon-carbon compo-cast composite using the effect of the friction's stir processing parameters. They concluded that an increase in the number of passes through FSP increased the effect of hardness & toughness. Rotational speed also had a direct impact on UTS and hardness. By increasing the rotation speed, UTS and hardness also increased but no impact on toughness was observed. Mehtedi et al. [25] analyzed the recycling of AA1090 aluminium alloy chips in the form of FS back extrusion process. They derived that FSE used to recycle AA1090 chips gives a good surface finish, but contains small voids and non-homogeneous microstructure.

Ingarao et al. [26] analyzed the energy consumption of energy required in aluminum alloy recycling by using the friction stir extrusion process. It was concluded that FSE reduced the primary energy demands from 53% to 33% wt of the re-melting route and ECAP route. Dinaharan et al. [27] produced AMCs by mixing copper powder with molten aluminum. They improved the microstructure and tensile strength using FSP. They derived that FSP increases the tensile strength of composites because of the considerable change in microstructure and surface of fracture showing a positive change in ductility and FSP increases the dislocation density because of high thermal misfit and plastic deformation. Sarkari et al. [28] analyzed the mechanical properties and texture variations of an Al during high plastic deformation and FSP with SiC particles. It was determined that the application of FSP to the severely changed shape of aluminium caused enormous grain growth in the stir zone and sub-grain structure deterioration. As SiC nanoparticles combine during FSP, grain boundaries may be pinched, resulting in a finer grain of stir zone.

Chainarong at al. [29] worked on improving the mechanical characteristics of shear strength and metallurgy of 356 aluminium alloy by FSP. It was concluded that the maximum tensile strength after FSP is equal to 188.57 MPa, a jump of 11.8%. It was discovered that the maximum properties were observed at rotation speed of around 1750 rpm and traverse speed of 160 millimeters per minute. Huang et al. [30] analyzed Nickel-Titanium memory alloy particles reinforced aluminium matrix composites by underwater FSP. It was concluded that structure having fine grain, which is dispersed and well-bonded in UFSP AMCs greatly increased strength without severely changing the ductility. Sorgente et al. [31]used the primary FSP test parameters to analyze the impact of FSP on the strain behavior of a Al (thickness of superplastic Al sheet=1.35 mm). It was concluded that when working on a superplastic sheet having speed equal to 1000 rpm, the material changes shape by taking a long time compared to the base material because of too much heat of friction.

Das et al.[32] studied the residual stresses of friction stir welding Al 5083 test specimen and mechanical properties and wrapped up that these properties are governed by the thermal input rather than by the mechanical deformation caused by the FSW tool. Elangovan and Balasubramanian [32] evaluated the impact of various tool geometries and rotating rates on the effectiveness of welded joints.

To study, they used tensile tests and macrostructure analyses the connection between mechanical properties and FSW parameters. The analysis revealed that the correlation between the static and the dynamic volume of the pin has a significant impact on the weld's quality. Ren et al. [32]examined how welding speed affected the distribution of micro-hardness in the cross-section of an FSW weld. Also, the correlation between the hardness distribution and the fracture direction during the tensile test was examined.

Pan Y,Wang et al. [33] discovered that the 7N01 aluminium alloy exhibits discontinuous distribution of grain boundary precipitates can enhance SCC performance by preventing the development of anodic corrosion channels. Sunada et al. discovered that under stress, the charge transfer resistance of the 7075 aluminium alloy was much lower.by connecting the testing machine and the electrochemical impedance spectroscopy test.

Santella et al. [34] reported that the tensile properties of multiple-pass FSP A356 and A319 was improved in comparison to the base metals as-cast. employed 12.5 mm-gauge tensile specimens that spanned the whole FSP area. Using this in engineering applications is quite beneficial. Elnabia et al. [35] The accuracy of the output result obtained is based on UTS, which is 97.6% and 99.5% for mean and S/N ratio, respectively. MINITAB was used to compare the outcome with parameters of efficiency and strength using their S/N ratio. The joint strength is mostly determined by the welding parameters, including tool shoulder diameter, tool rotating speed, welding speed, and axial force.

Conclusion

Many researchers have performed FSP on various Aluminium alloys and observed the enhancement in their properties. It was observed that aluminium alloys can have their traits and attributes increased through the FSP. The impacts of these advancements are used in various sectors like in the manufacturing, automotive, and aerospace sectors. Enhanced factors such as hardness, tensile strength, reduction in weight and corrosion resistance were observed by various researchers. The size, aspect ratio, and distribution of the Si particles were unaffected by FSP. The FSP-broken Si particles were evenly dispersed across the whole processing zone that multiple-pass FSP formed.

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