IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology
Vol. 8, Issue 3, March 2021

DOI: 10.17148/IARJSET.2021.8332

Friction Stir Processing (FSP) of surface composites used in aerospace & automobile components

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Abstract: Nowadays, there is increasing demand for operating properties of manufactured components but with reducing mass of a structure which triggered manufacturing technology to find a new fabrication methodology of surface layers that exhibit the indispensable functional properties. Friction stir processing (FSP) of surface layers is a new method which was developed by Welding Institute (TWI) in the year 1991 which is situated in Great Britain. The Friction Stir Processing technique is primarily employed for the restructuring of microstructure in layers close to the surface of processed metallic components and has a high future prospective in the field of superplasticity and metal matrix composites. Particularly, the procedure may result in: surface composite, high quality and smooth grained structure, modification of cast alloys at a microstructural level, alloying with specific elements, refinement of the quality of the welded joints. This review study focuses on the alloying process with the help of friction stir processing of aluminium as well as magnesium along with different reinforcements. The study consists of the outcomes of multiple reinforcement addition methods which affect the components in terms of mechanical and tribological properties. The results establish that the ultimate tensile strength, strain rate and wear and corrosion resistance are boosted by the incorporation of reinforcements.

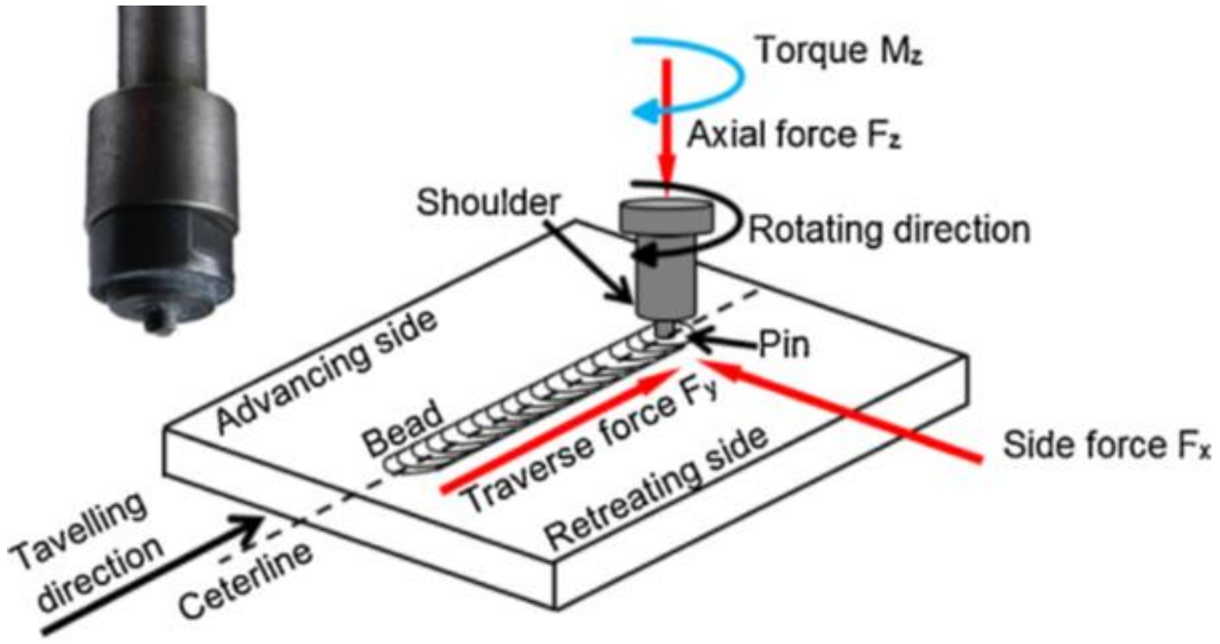
Keywords: Aluminium Alloy, Magnesium Alloy, Friction Stir Processing

I. INTRODUCTION

Reinforcement of Metal-matrix composites with ceramic phases demonstrate improvements in various properties including strength, elastic modulus, creep and fatigue, and resistance to wear because of which they are considered favourable structural materials for many industries such as aerospace and automobile[1]. Because of the inclusion of ceramic reinforcements which are non-deformable, these composites also endure from a reduction in ductility and toughness, as a result of which their wide applications are limited to a certain extent[2]. In such components wear resistance plays a major role due to surface properties of these components could be overcome by utilising ceramic phases in order to reinforce the surface layer of components while the major proportion of components hold on to the initial composition and structure with greater toughness[3]. Spray deposition, squeeze casting, vapor deposition, stir casting, powder metallurgy, in situ fabrication and diffusion bonding are some of the numerous methods that have been developed by engineers for the fabrication of MMCs[4]. Melting of base material during the fabrication process, however, is one of the most prominent drawbacks of these techniques[5].

In recent years, a new technique called Friction stir processing has contemporarily been used by scientists and engineers in order to generate modifications of the metal surface at a microstructural level. FSP is a solid state technique which is stemmed from friction stir welding used for producing surface composites by changing the surface microstructure. These reinforcements act as secondary phase particles that can be incorporated into the matrix during Friction Stir Processing. Another advantage of FSP over other techniques is that FSP helps to achieve a finer grain structure [6]. The FSP technique involves plunging a pin into the modified material with the rotating tool's shoulder adjoining the base metals. The rotation of the shoulder under the influence of an applied load heats the metal surrounding the modified area as the tool (Fig. 1) transverses the modified direction, and the modified area is formed as the metal from each section flows because of the rotating action of the pin. The sway of material flow, plastic deformation and increased temperature are the causes behind the development of the microstructure during the FSP process, and it is distinguished by a central stir zone surrounded by a thermo-mechanically affected zone (TMAZ) and a heat affected zone (HAZ). The deformed material is relocated to the advancing side (AS) from the retreating side (RS) of the tool pin and is forged by the tool shoulder, leading to the formation of a solid state modification of the material. The area having the highest importance in the FSP technique is between the stir zone and thermo-mechanically affected zone (TMAZ). The properties of the modified area, especially adhesion area determined by this area. Whereas, in case of Friction Stir Welding, the most important area is the stir zone. The difference in the areas having highest importance is the key differentiating factor between the FSP and the FSW processes. In the case of FSP, the important area is the zone immediately below the pin, while for FSW it does not matter because basically the welding technology consists of joints throughout the thickness of materials. This is the second difference between the two technologies.

Rotational speed, tilt angle, travelling speed, penetration depth of the tool, kind of the tool (diameter and shape of the pin, pin length, diameter and shape of the shoulder), cooling system, alloying material (SiC, Al_2O_3, etc.), and clamping systems act as the main technological specifications for the FSP process [7].



(Fig 1- Friction Stir Processing process and its tool with pin) [34]

Localized heating as a result of Friction betwixt the tool and workpieces leads to softened and plasticized workpiece. The movement of the materials from the front of the pin to the back of the pin leads to the generation of a volume of processed materials[8]. This process involves the material to go through intense plastic deformation and this leads to substantial refinement of the grains. Possible applications of FSP include generation of microstructure which is amenable to high strain rate superplasticity. [9].

FSP technology can be used in the present day advancement of technological revolution. The alloys of Aluminium, Magnesium, Silicon are widely used in automobile and aerospace industries for its wide variety of properties which is beneficial in this industrial revolution. In aerospace, components are desired to have material properties such as high reliability, light weight , ductile , corrosion resistant and also focus on aerodynamic performance as well as suitable for different weather conditions. [10]. In automobiles, lightweight materials that can make a substantial contribution to enhanced fuel consumption, thus, the components are desired to have lower weight, as a 10% decrease in the weight of the vehicle translates to a 5.5% betterment in fuel economy of the vehicle. The piston pin, piston, connecting rod and connecting rod bearing comprise the piston assembly, and account for a major percentage of the frictional losses in an automobile engine thus accounting for an appreciable recognition in terms of lightening of weight[11].

Thus, FSP can be beneficial in manufacturing of these components.

II. LITERATURE REVIEW

This study reviews the experimental analysis that has been performed by various researchers on the emerging technique in the field of manufacturing technology. This paper mainly focuses on the mostly aluminium, magnesium and its alloys that are refined to achieve better results when used as components in aerospace and automobile industry. This analysis can be studied on different parameters like the material of the tool, tool with different dimensions and tool rotational speed. Main parameter which is considered in this paper is the rotational speed of the tool which makes contact with the workpiece. Aluminium alloys are widely used and studied in this domain. AA6082 is an aluminium alloy with the chemical composition Magnesium, Manganese, Silicon and iron when reinforced with Ceramic particles

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of different grades like SiC, TiC, B4C, Al2O3 and WC at a rotational speed of 1600 rpm and axial load of 10kN gives superior hardness and wear resistance for ceramic reinforcements [12]. AA6082 is also reinforced with Stainless Steel (316L) with different percentages of volume under the same parameters to give fine grain and enhanced tensile strength to the material [13]. Aluminium alloy AA1050 contains about 99.5 % of Aluminium and rest is copper and iron, when reinforced with Titanium Carbide (TiC) at a rotational speed of 1200 rpm, improves as well as enhances the hardness and also increases wear resistance of the material [14].

AA1050-H24 aluminium where H24 Means the temper(heat treatable alloy) when reinforced with iron (Fe) of 4 µm, magnetite (Fe3O4) of 180 µm particles and SiC as well as Al2O3 particles (of about 1.25 mm) at a rotational speed of 1000-2000 rpm gives an evenly distributed and an uniform surface homogenous of reinforced particles in the nugget zone at 1000 rpm which is achieved after three times[18]. AA5083 alloy has a chemical composition Magnesium, Manganese, Copper and Iron, when reinforced with B4C/SiC/TiC either of the material or in combination, at a rotational speed of 800 rpm without pin and with pin at a rotational speed of 600 rpm, improves hardness, tensile and wear properties are achieved [15]. AA5083 when reinforced with Alumina particulate and rotation of the tool is taken as 1120 rpm which gives uniformly scattered region of the aluminium alloy, good bonding affinity with the base plate and has increased hardness profile of the material [16]. AA5083 when reinforced with Ni particles of 20 µm and Cu particles at a rotational speed of 1000-1600 rpm gives increase in strength as well as grain refinement is also achieved [19]. AA6061 aluminium alloy also known as “Alloy 61S ” is precipitation hardened alloy when reinforced with Silicon Carbide (SiC) (about 50 nm) at a rotational speed of 800-1600 rpm gives higher tensile strength to the material [17].

AA6061 (a plate of 6 mm thickness considered) when reinforced with SiC and Graphite powder of 100 and 44 µm, respectively at a rotational speed of 1800, 2200, and 2500 rpm gives the best as well as uniform mechanical properties. [21]. AA2024 aluminium alloy consist of copper, manganese, magnesium and some other material such as zinc, lead, nickel, chromium, bismuth and silicon which are less than a percent makes the composition of this alloy (a plate of thickness 3.5 mm considered) when reinforced with Al2O3 of 30 nm nanoparticles and processed at different rotational speed gives an improvement in Ultimate Tensile Strength(UTS) and an increase in hardness of about 25%-46% is also achieved [20]. AA1100 alloy consists of more than 99% of aluminium, when reinforced with Ti-6Al-4V (about 35nm) at a rotational speed of 600 and 1200 rpm, increase in strength of material, evenly scattered particles of the surface and decrease in pilling of particles in the specified region are also achieved [22]. AA6063 aluminium alloy consists of Iron, Magnesium, Silicon, and Zinc when reinforced with TiO2 (about 0.56 µm) which different volume percentages and processed at a rotational speed of 1600 rpm, decrease in the size of the grain particles and an increase in interfacial bonding is found. When the particle content of TiO2 is about 18 vol% or more, there is a decrease in strength of the material when in tension[23].

Magnesium alloys are the second most used in this use and the interest of this study lies in knowing about the changes happening on the surface of these alloys after friction stir processing. AZ31 is magnesium alloy which contains Aluminium, Zinc and Manganese when processed at a rotational speed of 1000-1800 rpm gives a temperature rise during the friction stir processing. It was also, maximum temperature could reach as high as 250–450 °C, depending upon tool rotation speed [24]. AZ31 when reinforced with SiC powder which was filled into a groove, then processed at a rotational speed of 1500 rpm gives refined grains of SiC particles and an increase in the hardness at micro level of the stir zone of about 80 HV[25]. AZ31 when reinforced with ZrO2 and SiO2 which are particles of nano-size, in volume percentage of about 15% and 8-9% respectively when processed at a rotational speed of 800 rpm gives the distribution of these particles at depth of 20nm and was competently uniform after four FSP passes. The tensile properties and hardness improved significantly at room temperature of the AZ31 composites after the FSP process [27].

AZ31 when reinforced with Al2O3 particles with mean diameters of 35 nm , 350 nm and 1000 nm respectively, was processed at rotational speed of 800, 1000 and 1200 rpm. Increase in Tool rotation results in greater input of heat, which affects the size of particles of the base alloy which increases the effect of rotation and leads to better nanoparticle distribution, This effect can be increased by increasing no. of passes, nanoparticles size and the distribution of these particles was also obtained. [29]. AZ31 when reinforced with Multiwalled Carbon Nanotube, processed at a rotational speed of 1500 rpm shows an increase in hardness mainly because of high interfacial strength and grain refinement at the carbon nanotube interface. Under an applied load of 20N, AZ31 alloy containing carbon nanotubes, wear resistance was doubled which overall bettered the material properties significantly [33]. AZ91 alloy consists of aluminium and zinc in combination of less than 10 %, when reinforced with Al2O3 powder with three different sizes (ranging from nano-meter to micrometer scale) 3000, 300, and 30 nm processed at different rotational speed. Grain structures had equiaxed and fine grains particles were achieved because of the structural change of the crystal in the SZ while alumina particles of nano-sized dispersed in a distinct manner because of dissimilar stirring action.

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The cluster size and the size of particles in the sample formed by the tool of triangular shape which is less than that of the tool with square shape which affected the properties of materials [28]. Pure magnesium castings processed at a rotational speed of 400, 500, 630, 800, 1000, 1250 rpm respectively. The hardness surged in the FSP specimens compared with the obtained pure Mg castings. [30]. Mg–Al–Zn cast alloy is processed for a tool rotation of 1000-1800 rpm. The result after the process displayed an ultimate tensile strength of 337 MPa and about 10% of extension under tension [26]. Mg–Y–Nd–Zr (WE43) casting alloy when processed at a rotational speed of 800 rpm. The properties of this alloy improved significantly after friction stir processing. High temperature tensile tests showed that the alloy after being processed has excellent High Strain Rate Superplasticity (HSRS) and substantial elongation at 748 K of about 631% [31]. Mg–Y–Zn casting alloy when processed at a rotational speed of 450 and 600 rpm. This results in fine grain particles, higher hardness of 120 HV and finer structure was also observed [32].

III.DISCUSSION

Friction stir processing technology is one the emerging technology in the field of manufacturing technology and an extension to previous friction stir welding technology. In this review, friction stir processing is considered for the alloying process of mixture of materials in different compositions. In this process, the base material is processed with elements to improve its mechanical properties. The properties like ductility, wear resistance, hardness, strength, corrosion resistance and crystals/grains of the surface can be improved in the material by disturbing the base or substrate material or properties of the material. This technology is nowadays widely used in production of surface composite in aluminium and magnesium alloys with different material or machining conditions. This emerging technology is also used for composites with high melting points as well such as titanium or copper alloys can be processed.

Reinforcements of the different materials can be in the form powder or similar to base plate as well. Fabrication of the surface composites by groove or drilling holes on the base is the most common method used in this technique. The groove is machined on the surface of the base metal and the material which is to be reinforced is filled in it and then the friction stir processing machine which is taken as without is used in closing the groove and make it similar in appearance to the original base plate. Lastly, the machine with a pin is applied to obtain the desirable mechanical properties of the material. There is one another by covering the base plate with thin film of another metal. In this study, different combinations of reinforcements used in the fabrication of aluminium alloys and magnesium alloys are studied and how this process affects the performance of the materials or alloys used in the field of aerospace and automobile and its different components.

Experiments show that most of the reinforcements with help of powder using the concept of powder metallurgy and second most used method is based on grooving the alloying material. These experiments have shown and proven that these materials and its composites have potentials and are most suitable for industrial use where mechanical properties and precision of the material plays a vital role. Experimental analysis showcased that metallurgical as well as mechanical properties like modification of surface or improvement of hardness, creep or fatigue of the material and thermal and mechanical strength showed positive changes after processed at different machine and tool parameters. Due to the emerging technology some facts are still unknown to the researchers and can be found through these experiments such as wear of tool or two stuck together at undesirable places or determining the life of the welded portion to improve the fatigue resistance of the material and have longer life. In summary to this discussion, alloys of aluminium and magnesium can be used for production of components of aerospace as well as automobiles as the properties which are most desired and also proved by most of the researchers can be obtained after the friction stir process.

Aluminium and magnesium showed an excellent wear resistance, increase in hardness and also the ultimate tensile stress which is very beneficial for production of these components. Specific to the aerospace industry, these machines show excellent machinability, and have precision accuracy. Materials can be cast alloyed or can be forged alloys, this process can be used for the production of the components. When the same material reinforced with different materials showcased different properties after processing and showed the capability of being used for different components according to the need of the mechanical properties and other factors.

IV.FUTURE ASPECTS

As an emerging technology, it also has some defects which should be taken into account and should be cured with time. Friction stir processing has different heat zones which are prone to defect as this technology is an advancement of Friction Stir Welding. Some of the major defects which can be a drawback to this technology are as follows.

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a). Creation of Worm Hole- Mostly found in forged materials which are in longitudinal direction.The main cause of the defect is because of rotational speed of the tool.

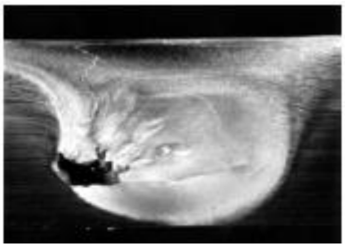

Fig.- Worm Hole [35]

b). Surfaces lack of Fill- It is a surface type of void which is formed on the advancing side. It is formed due to improper support mostly from backside or can be due to lack of temperature.

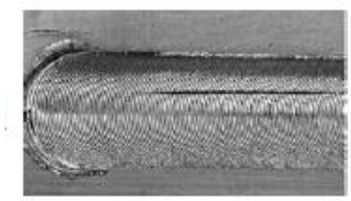

Fig. Surface Defect [35]

c). Nugget Collapse- It is formed due to imperfect formation of the crystals in the nugget zone. Mostly due to very hot weld or due to high inflow of material.

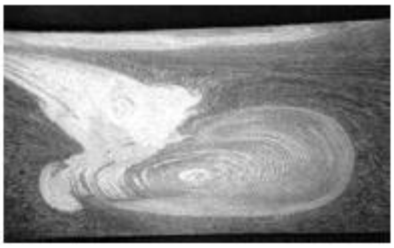

Fig. Nugget Collapse [35]

These are some of the major defects which should be researched and have proper remedies for these defects which can cause failure of these components when installed in different locations. Another major issue which arises due to wear in the tool of friction stir processing which is found when material of high melting point such as steel when reinforced with composites of ceramic particles such as tungsten. More study has to be conducted on these aspects as well. One of the last and most important viewpoints is the cost spent on this process. This is the process which limits the usage of this process. This the major reason for alloying of aluminium and magnesium is focused more for manufacturing using friction stir processing. This material is beneficial in production of components used in cars ranging from small utility vehicles to high utility vehicles and to components of aeroplanes such as boeing 727 and helicopters as well due to properties obtained after friction stir processing .

Arbegast et. al.(2008), discussed all these defects caused due to friction stir processing.[35]

DOI: 10.17148/IARJSET.2021.8332

V. CONCLUSION

Friction stir processing has become a multifaceted technique for the manufacturing of surface composites. Because of the substantial amounts of plastic strain in Friction Stir Processing it provides the proficiency of distribution of particles on the surface. It leads to exceptional improvements in the properties like Wear resistance, Microhardness, Strength and Young's modulus, and Grain refinement. In this review, material properties are studied of different alloys which are used in manufacturing aerospace and automobile components through Friction Stir processing. Materials properties showed noticeable changes which could be beneficial for these components due to precision, wear and corrosion resistance properties which are required for these components. Aluminium and Magnesium alloys are majorly studied in this review. The formation of surface composite layers of Nano reinforcement particles by the FSP technique on aluminium alloys or magnesium alloys improves numerous properties including corrosion resistance, tensile behaviour, hardness, percentage and wear resistance behaviour of the workpiece material. Moreover, raising the tool rotational speed leads to larger heat input and also enlarges grain size of the metal alloy and results in better distribution of nanoparticles.

REFERENCES

1). Wu, H., Li, Y., Tang, X., Hussain, G. and Adetunla, A. (2015). Nano-mechanical characterization of plasma surface tungstenized layer by depth-sensing nanoindentation measurement. Applied Surface Science, 324,160–167.
2). Yashpal, K., Chandrashekhar, J., Ajay, V. and Suri, N. (2017). Fabrication of aluminium metal matrix composites with particulate reinforcement: A review. Materials Today: Proc. 4, 2, 2927–2936.
3). Anbuchezhiyan, G., Muthuramalingam, T. and Mohan, B. (2018). Effect of process parameters on mechanical properties of hollow glass microsphere reinforced magnesium alloy syntactic foams under vacuum die casting. Archives of Civil and Mechanical Engineering18, 4, 1645–1650.
4). Kumar, A., Kumar, S. and Mukhopadhyay, N. K. (2018). Introduction to magnesium alloy processing technology and development of low-cost stir casting process for magnesium alloy and its composites. J. Magnesium and Alloys 6, 3, 245-254.
5). Sahoo, B. N. and Panigrahi, S. K. (2018). Effect of in-situ (TiC-TiB2) reinforcement on aging and mechanical behaviour of AZ91 magnesium matrix composite. Materials Characterization, 139, 221–232.
6). Dixit, M., Newkirk, J. W. and Mishra, R. S. (2007). Properties of friction stir-processed Al 1100-NiTi composite. Scripta Materialia 56, 6, 541–544.
7). R.M. Miranda, J. Gandra, P. Vilaça, Surface modification by friction based processes, in: Modern Surface Engineering Treatments, InTech, 2013
8). R.S. Mishra, M.W. Mahoney, S.X. McFadden, N.A. Mara, A.K. Mukherjee, Scripta Mater. 42 (2000) 163
9). R.S. Mishra, M.W. Mahoney, Mater. Sci. Forum 357-359 (2001) 507
10). P D MANGALGIRI, Composite materials for aerospace applications, Bull. Mater. Sci., Vol. 22, No. 3, May 1999, pp. 657-664
11). F. H. Froes , Advanced metals for aerospace and automotive use. Materials Science and Engineering, A 184 (1994) 119-133
12). I. Dinaharan, "Influence of ceramic particulate type on microstructure and tensile strength of aluminium matrix composites produced using friction stir processing," J. Asian Ceram. Soc., vol. 4, no. 2, pp. 209–218, 2016.
13). S. Selvakumar, I. Dinaharan, R. Palanivel, and B. G. Babu, "Development of stainless steel particulate reinforced AA6082 aluminum matrix composites with enhanced ductility using friction stir processing," Mater. Sci. Eng. A, vol. 685, no. January, pp. 317–326, 2017.
14). R. S. Mishra and Z. Y. Ma, "Friction stir welding and processing," Mater. Sci. Eng. R Reports, vol. 50, no. 1–2, pp. 1–78, 2005.
15). V. K. S. Jain, P. M. Muhammed, S. Muthukumaran, and S. P. K. Babu, "Microstructure, Mechanical and Sliding Wear Behavior of AA5083–B4C/SiC/TiC Surface Composites Fabricated Using Friction Stir Processing," Trans. Indian Inst. Met., vol. 71, no. 6, pp. 1519–1529, 2018.
16). V. Sharma, U. Prakash, and B. V. M. Kumar, "Surface reinforcement of AA5083-H111 by friction stir processing assisted by electrical current," J. Mater. Process. Tech., vol. 224, pp. 117–134, 2015.
17). M. Salehi, M. Saadatmand, and J. Aghazadeh Mohandesi, "Optimization of process parameters for producing AA6061/SiC nanocomposites by friction stir processing," Trans. Nonferrous Met. Soc. China (English Ed., vol. 22, no. 5, pp. 1055–1063, 2012.
18). E. R. I. Mahmoud and M. M. Tash, "Characterization of aluminum-based-surface matrix composites with iron and iron oxide fabricated by friction stir processing," Materials (Basel)., vol. 9, no. 7, 2016.
19). R. Bauri, G. D. Janaki Ram, D. Yadav, and C. N. Shyam Kumar, "Effect of Process Parameters and Tool Geometry on Fabrication of Ni Particles Reinforced 5083 Al Composite by Friction Stir Processing," Mater. Today Proc., vol. 2, no. 4–5, pp. 3203–3211, 2015
20). E. Moustafa, "Effect of Multi-Pass Friction Stir Processing on Mechanical Properties for AA2024/Al2O3 Nanocomposites," Materials (Basel)., vol. 10, no. 9, p. 1053, 2017.
21). A. Sharma, V. M. Sharma, S. Mewar, S. K. Pal, and J. Paul, "Friction stir processing of Al6061-SiC-graphite hybrid surface composites," Mater. Manuf. Process., vol. 33, no. 7, pp. 795–804, 2018.
22). Adedotun Adetunda and Esther Akinlabi, "Mechanical characterization of Al/Ti-6Al-4V surface composite fabricated via FSP: A comparison of tool geometry and number of passes," Mater. Res. Express, pp. 1–21, 2018.
23). S. Joyson, A. Isaac, D. Jebaraj, D. Raja, S. Esther, and T. Akinlabi, "Microstructural Characterization and Tensile Behavior of Rutile (TiO2) - Microstructural Characterization and Tensile Behavior of Rutile (TiO 2) - Reinforced AA6063 Aluminum Matrix Composites Prepared by Friction Stir Processing," Acta Metall. Sin. (English Lett., no. August, pp. 1–12, 2018.
24). Chang, C. I., Lee, C. J., & Huang, J. C. (2004). Relationship between grain size and Zener – Holloman parameter during friction stir processing in AZ31 Mg alloys, 51, 509–514.
25). Morisada, Y., Fujii, H., Nagaoka, T., & Fukusumi, M. (2006). Effect of friction stir processing with SiC particles on microstructure and hardness of AZ31, 433, 50–54.
26). Materialia, S., Natural, N., Foundation, S., No, G., Sciences, F., & View, C. A. S. (2007). Enhanced Mechanical Properties of Mg-Al-Zn Cast Alloy via Friction Stir Processing.
27). Chang, C. I., Wang, Y. N., Pei, H. R., Lee, C. J., Du X. H., Huang, J. C., (2007). Microstructure and Mechanical Properties of Nano-ZrO2 and Nano-SiO2 Particulate Reinforced AZ31Mg Based Composites Fabricated by Friction Stir Processing 2015.
28). Faraji, G., Dastani, O., Mousavi, S.A.A.A. (2011). Microstructures and mechanical properties produced by friction stir processing Effect of Process Parameters on Microstructure and Micro-hardness of AZ91 / Al 2 O 3 Surface Composite Produced by FSP).

IARJSET

ISSN (Online) 2393-8021
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International Advanced Research Journal in Science, Engineering and Technology

Vol. 8, Issue 3, March 2021

DOI: 10.17148/IARJSET.2021.8332

29). Azizieh, M., Kokabi, A. H., & Abachi, P. (2011). Effect of rotational speed and probe profile on microstructure and hardness of AZ31 / Al 2O 3 nanocomposites. JOURNAL OF MATERIALS & DESIGN, (April).
30). Journal, I., Azizieh, M , Bahadori, R., Abbasi, M., Yoon, E. Y., Kim, H. S. (2016). Effect of friction stir processing on the microstructure of pure magnesium castings Effect of friction stir processing on the, (December 2015).
31). Li, J., Zhang, D., Chai, F., Li, J., Zhang, D., & Chai, F. (2017). Influence of processing speed on microstructures and mechanical properties of friction stir processed Mg – Y – Nd – Zr casting alloy.
32). Morishige, T., Tsujikawa, M., Hino, M., Hirata, T., Oki, S., Higashi, K., Higashi, K. (2017). Microstructural modification of cast Mg alloys by friction stir processing.
33). Jamshidijam, M., Akbari-fakhrabadi, A., Morteza, S., Hasani, G. H., Mangalaraja, R. V, Jamshidijam, M., Masoudpanah, S. M. (2013). Wear Behaviour of Multiwalled Carbon Nanotube / AZ31 Composite Obtained by Friction Stir Processing.
34). Marek Stanisław Węglowski, Friction stir processing – State of the art. Archives of civil and mechanical engineering 18(2018) 114 – 129.
35). Arbegast, W.J., 2008. A flow-partitioned deformation zone model for defect formation during friction stir welding. Scripta Mater. 58, 372–376