A Study on the Fabrication of Metal Matrix Composite Fabricated by Friction Stir Additive Manufacturing (FSAM)

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Abstract

Metal additive manufacturing has a field of possibilities in the aerospace and automotive industries. The majority of these procedures are fusion-based, which has the disadvantage of solidification concerns and isn't suitable for all alloys. Friction stir additive manufacturing (FSAM) is a collection of cutting-edge techniques for stripe-by-stripe material additive manufacturing based on the friction stir welding idea. This method is recognized as a progress in the field of metal additive manufacturing because to the benefits of solid-state welding, which are inherent to these processes (MAM). The research highlights recent accomplishments in the mostly unknown field of friction stir additive manufacturing (FSAM), discusses the FSAM's key technologies, and emphasizes the advantages of FSAM over fusion-based alternatives. The future of Friction stir additive manufacturing technologies in the realm of industrial production is also discussed, as well as its potential. The study comes to a close by showcasing some of the most important academic publications on the subject.

Keywords:Additive Manufacturing, Friction stir additive manufacturing, Solid state welding, Metal Matrix Composite, Friction Stir Processing.

1. Introduction

Since the early 1960s, there has been a desire for new and superior engineering materials, with a focus on the automotive and aerospace sectors. Some MMCs, such as Al-MMCs and Mg-MMCs, were substantially lighter than metals and alloys, forcing a quick development of metal matrix composites.The use of mixed Al and Mg alloys provides for higher ductility and a higher strength-to-weight ratio **[1-3].** Manufacturing of two distinct metals and non-metals, such as Steel-Mg, Steel-Al, and Al-Mg for weight reduction, has been classified as vital in materials fabrication techniques.Dissimilar material combining offers a number of benefits and applications, such increased energy savings, reducing costs, as well as the ability to 'tailor' the composites design in a given aerospace sector. The need for lighter materials in the automotive and aerospace sectors is growing at an exponential rate**[4-5]**.The demand for Al alloys and Mg alloys in multi-material structures has been constantly rising. Both the metals are frequently utilized in aerospace and automotive engineering because of their multiple benefits, which include superior mechanical properties, reduced density, and reusability.However, a few particular benefits may include Al (for better strengths characteristics and creep resistance) as well as Mg (for higher damping capacity), and therefore these features are combined to achieve the best of both worlds **[6-8]**.Additive manufacturing (AM) has evolved amongst the most exciting topics of interest in recent decades, including a wide variety of activities ranging from machine design to diverse material properties. AM is a crucial resource developed in Industry 4.0.Figure 1 depicts the various technologies and techniques for Industry 4.0. Additive manufacturing is a technological process which concern layer-by-layer material inclusion to produce a 3D product of any pattern or size (complex object), if the raw material is metallic, polymer, human tissue, or other materials**[9]**.In the fields of vital engineering, such as medical, construction, aircraft, and automotive, additive manufacturing has seen exponential development and is presentlyused as a fast-growing manufacturing technique**[10-11]**.AM for metallic components employing procedures like as electron beam melting as well as selective laser melting involves layer-by-layer addition of a composite material or metallic, which is accomplished through melting and solidifying powders, leading in relatively close components.The essential benefits are provided by these processes: less segregation, finer second phase particles, as well as non-equilibrium phases, resulting in a very rapid rate of cooling.Fusion-based additive methods are being employed for a wide range of applications, from prototype to end-product manufacturing.Due to the lack of melting, friction stir additive manufacturing (FSAM) techniques

minimize solidification-related faults such as porosity, shrinkage, fractures, and other deficiencies, and solve the disadvantages of fusion-based additive manufacturing **[12-15].**

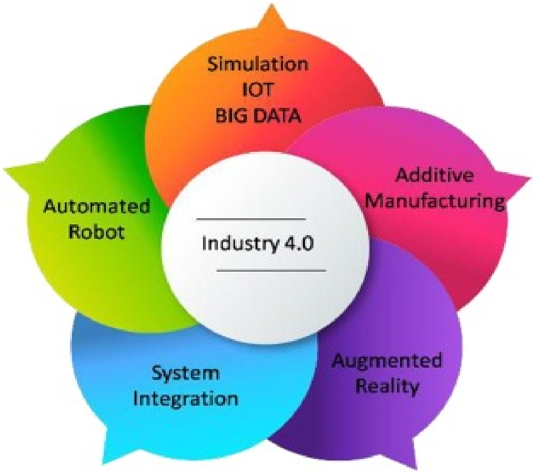

Figure 1 the various technologies and techniques for Industry 4.0**[9].**

FSAM is a relatively basic and low-cost technology. Many metals as well as alloys have been successfully processed using friction stir additive manufacturing.FSAMmakes advantage of frictional heating by friction between the tool and the base material (BM), which softens the materials, that producesDynamic recrystallization& plastic deformation of this base material. The Dynamic recrystallization caused by the tool's stirring action results in refined grains that are subjected to significant deformation and heat input.The effect of friction stir processing process factors namely, rotational speed, traverse speed and axial force**[16-17]**.The researcher discovered the highest mechanical performance for a certain combination of parameters by improving the process parameters.Grain refining and microstructure homogenization can be accomplished in a single pass. Changing the heat input during processing can control grain refinement. Microstructural analysis was performed on FSAM to detect the location of internal faults and defects, investigate reasons of inadequate strength, and grasp the material flow process. Optical microscopy was employed to examine microconstituent and grain structures and morphology **[18- 20].**

This paper's scope encompasses not just AM technology configuration but also numerous additional configurations documented in the literature. This review study examines a significant number of reputable research publications in many aspects, particularly for Al-Mg dissimilar FSAM joining. The following major areas have been covered: heat production and fundamental joining mechanisms, followed by mechanical as well as microstructural characteristics. Furthermore, the report critically evaluated the impact of FSAM process parameters, related flaws, diverse applications, and suggested crucial concerns for future research.

2. Friction Stir Additive Manufacturing

White mentioned the possibilities of friction stir joining as an Additive Manufacturing(AM) technology in his 1999 applied and patent. Thomas etc.Al presented a similar technique in 2005**[20].**TWI Ltd is working on a revolutionarynear-net shape prototyping technology. Rapid prototyping is the most common name for a group of similar additive technologies used to create real items immediately from sheet or powder material. These technologies are distinct in that they combine and connect materials in layers to form objects.When compared to traditional subtractive production processes such as milling or turning, near net structure additive technologies provide benefits in a variety of applications.Objects with geometric complexity or sophistication can be produced without the requirement for costly machine setup, reducing machining waste, energy, and waste disposal.Some of the advantages of FSAM near net shape prototype processing approaches are listed. A high deposition rate may be achieved by utilizing a moderately thick plate. Working with both thin and thick sheet materials is possible**.** There is very little distortion. Three-dimensional processing technique Material can be changed to provide different attributes in different portions of the component. It is a solid-phase method that is not impacted by gravity and is made up of hot forged material that has been processed (most fast prototyping techniques are). This means that, if necessary, new sections might be 'grown' in situ on enormous, complex structures**[21-23, 30-34]**.Many technologies have been used and designed for rapid prototyping and net near shape manufacture. Fig. 2 shows how FSAM technology and stir approach may be used to make near-net shape components.

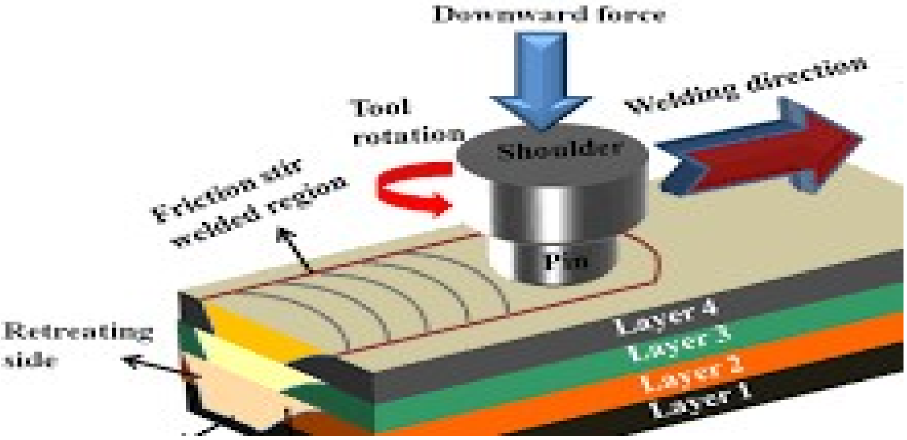

Fig. 2 Principle of Near-net shape manufacture by FSAM **[26].**

Friction stir welding (FSW) is a solid-state AM process this includes friction stir welding many plates one at top of the other[24-26]. It was originally shown by Airbus and Boeing, and it was marketed as a feasible another solid production methodcapable of achieving maximum speed at quicker production rates with reduced material waste. FSAM creates a weld by inserting an unusable rotating tool on rough / smooth metal sheets and then travelling along the joint line. Because of the heat producedbythe conflict between the tool and the contact area of the workpiece, material plasticizes and it flows circumferentially and axially around itrevolving tool to form the welds.The procedure is repeated until the required building height is achieved. In the aerospace industry, FSAM stands for stiffener-on-skin, which is typically machined from a large block of metal and has a low buy-to-fly ratio (weight of raw material/weight of the end product). Stiffeners/stringers manufactured from a blend of FSW/FSAM might be employed solid panels with multiple frames in the aerospace as well as aviation sectors. To minimize excessive conflicting temperatures and significant plastic degradation throughout the process, pin length and tool position should be carefully specified. The geometric diversity and precision of this production process enable it to form complex components. The macroscopic and microscopic structures of the created part are influenced by the geometry of the tool used in the FSAM process.

3. Microstructure

To achieve a stable fusion over numerous layers, friction stir-based AM technologies, such as FSAM, rely on the synergistic activities of high temperature, strain rate, and plastic flow of material. Important factors variables such as tool rotation rate, tool traverse speed, and tool material and design influence all from the above input variables.The multilayer depositions of Al5059/SiC aluminum alloy, as well as optical, microstructures, are shown in Fig. 3.Themicrographic picture of BM in Fig. 3 (b) displays elongated grains, which are the consequence of BM rolling. Following FSAM, grain size varies in different parts of the manufactured structure. The constructed build's NZ, TMAZ, and HAZ are shown in Fig. 3 (c). As a result of varied heat generation and severe plastic deformation at different areas of the tool and workpiece interfaces, these zones have diverse grain sizes (refer Fig. 3 c and d). The grain size in New Zealand is less than in TMAZ and HAZ. The fact that Al5059 is a non-heat treatable alloy with no predicted heat/annealing effects accounts for the smaller grain sizes in NZ.Figure 3 (e) depicts the dispersion of SiC particles at a specific construction position.Friction deposit of ultrafine and equiaxed grains were found. During the friction deposition process, the substrate material may be heated to 410°C, resulting in mild overegging. They discovered that when a material is subjected to plastic deformation, the dispersion density of the sample increased.Plastic flow at high temperatures caused by frictional heating changes the microstructure of the SZ and the HAZ in the FSAM. Specific morphological improvements, such as grain refinement, secondary phase formation, and precipitation, improve SZ and HAZ mechanical properties in some alloys while degrading mechanical qualities in others.

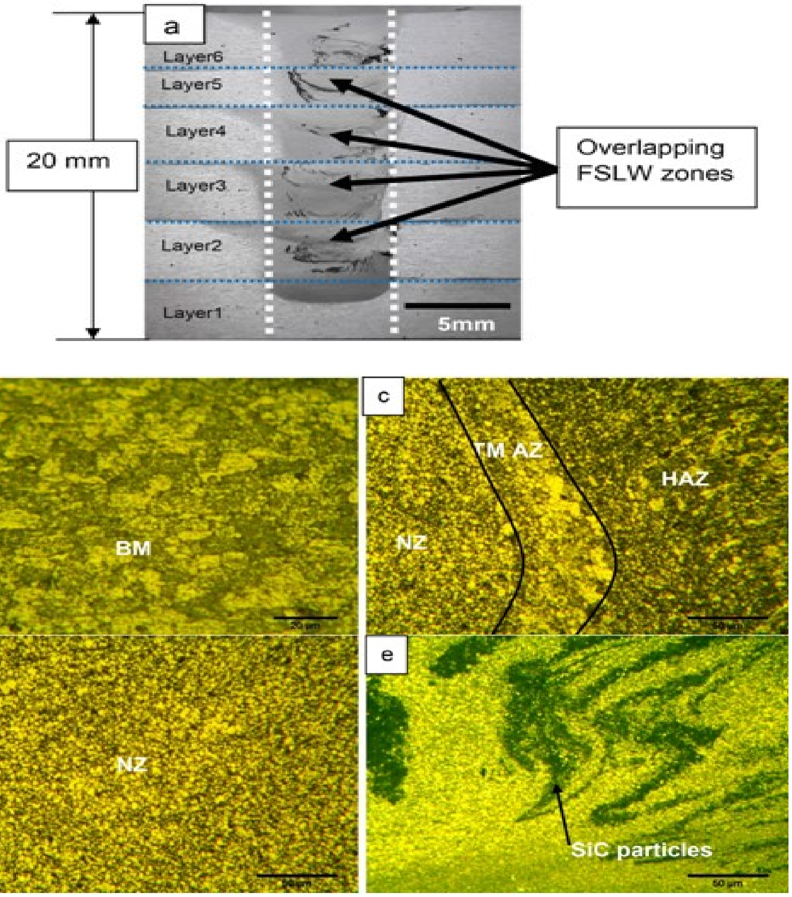

Fig. 3(a) macroscopic picture; (b) microscopic image of BM; (c) microscopic image of manufactured build; (d) microscopic image of NZ; (e) microscopic image of NZ revealing Sic particle dispersion[27].

4. Mechanical properties

The mechanical properties of materials are straightforward influenced by microstructures, notably dynamic recrystallization as a result of plastic deformation [30-34]. This finding is in line with the Hall Petch strengthening mechanism, which asserts that the grain dimension has an influence on the material's strength qualities. Most mechanical properties data, such as tensile, microhardness, fatigue strength, and so on, exhibited a tendency of rising specimen strength values in prior investigations. Palanivel et al. [29] compared the hardened profile of the folded and mature T5 ruffles the basicsand discovered an increase of 18% in hardness with an average of 104 HV (Fig. 4).

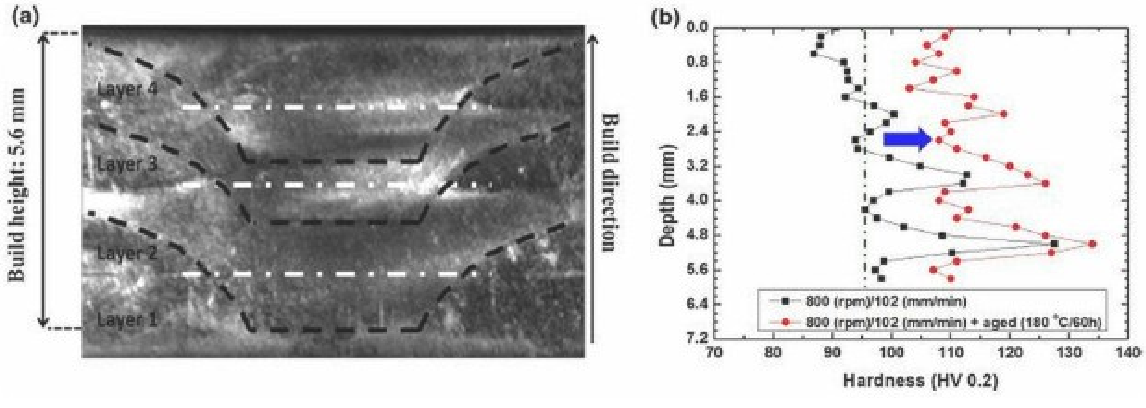

Fig. 4 Comparison of Vickers Hardness between the base material and the post-aged condition**[28]**

The yield strength (YS) of 267 MPa and the Ultimate Tensile Strength (UTS) of 362 MPa for FSAM's AA5083 alloy were obtained in tensile testing at 500 rpm and 152 mm/min, as shown in Fig. 5. The value of the fundamental material, on the other hand, is marginally lower, at 109 MPa and 336 MPa, respectively.

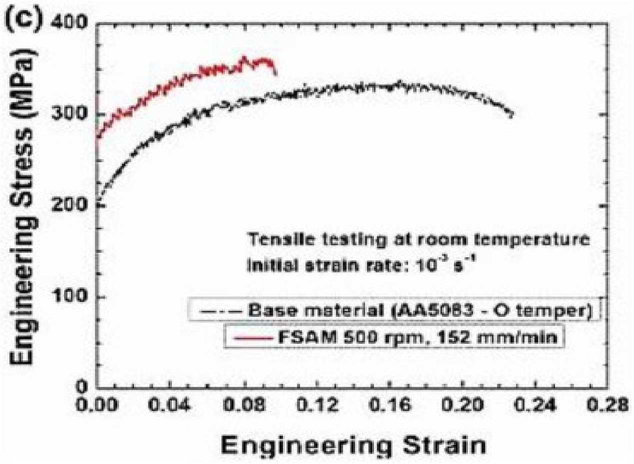

Fig. 5 Tensile profile among base material and friction stir additive manufacturing(FSAM) fabricated alloy using 500 rpm also 152 mm/min**[28].**

5. Conclusions

To conclude, we reviewed research publications on friction stir additive manufacturing, a developing solid-state additive manufacturing method. The following are the most important findings:

1. FSAM is capable of completely filling through-holes and wide grooves. This is especially true in the second instance, when the groove's diameter exceeds the feed rod's width by 33%.
2. Tensile testing at 500 rpm moreover 152 mm/min yielded a yield strength (YS) of 267 MPa and an Ultimate Tensile Strength (UTS) of 362 MPa for FSAM's AA5083 alloy, as illustrated in Fig. 5. The basic material, on the other hand, has a significantly lower value, measuring 109 MPa and 336 MPa, respectively.
3. The researchers discovered that the twisted as well as aged T5 temper has a rise in hardness of 18% when compared to the basic material, with an average hardness of 104 HV.

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