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MECHANICAL AND MICTROSTRUCTURAL EVALUATION OF AA1100 ALLOY FABRICATED BY FRICTION STIR ADDITIVE MANUFACTURING

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ABSTRACT: This paper presents an experimental study on Friction Stir Additive Manufacturing (FSAM) using AA1100 aluminium alloy and H13 tool steel. A vertical milling machine setup was employed to fabricate multilayer joints by stacking and lap-welding aluminium sheets using a tapered tool profile. The study explores mechanical properties including tensile strength, micro-hardness, and evaluates the resulting microstructure. Results show improved bonding, enhanced strength, and homogeneous grain structures across various process parameters. The findings demonstrate FSAM's potential for producing high-quality structural parts in aerospace and transportation industries.

Keywords: Friction Stir Additive Manufacturing, FSAM, AA1100, H13 Tool Steel, Microstructure, Mechanical Testing, Aluminium Welding

INTRODUCTION:

In recent years, additive manufacturing has become one of the most active research fields, encompassing everything from machinery design to the complex properties of materials. Engineers have been inspired and given new chances by the unparalleled topological design and on-demand printing capabilities. Despite the huge array of materials and technology available for AM, certain organizational principles can be used to categorize them. Naturally, the materials fall within the more general groups of polymers, metals, and ceramics. The class of materials of interest has a significant impact on AM technology.

The accelerating industrial transformation is driving up demand for a new class of particular engineered materials with specified qualities.

It results in new manufacturing techniques that are faster and more efficient than the conventional techniques created during the first and second industrial revolutions. The industrial revolution chronology and the concurrent expansion of the manufacturing sector are depicted in Fig. 1. Automated robots, automated assembly lines, guided vehicles, new and advanced materials, new manufacturing processes, new 3D printers, and sophisticated software like CAD, CAM, and CIM that connects the larger machines with the computer-controlled system are some of the key resources that are drastically altering the landscape of the manufacturing industry. Industry 4.0, or the fourth revolution, will adopt the automation and computer interface of the third and modify it with intelligent autonomous systems and machine learning.

The links between physical and cyber systems, the Internet of Things (IOT), big data, simulation, Augmented and virtual systems, and more are among the main resources of industry 4.0 (I 4.0). A more realistic 4.0 leads to smart manufacturing. One of the important tools created in Industry 4.0 is additive manufacturing (AM), which is currently a rapidly expanding production method. In crucial technical fields including medicine, construction, aerospace, and autos, additive manufacturing demonstrates exponential growth.

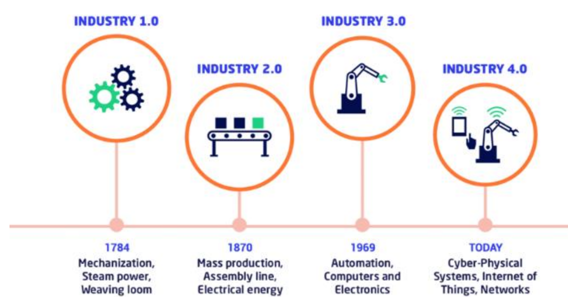

Figure : Industrial Revolution in manufacturing sector

Friction Stir Additive Manufacturing:

Friction stir welding is one solid-state welding technique. Friction stir welding creates friction as the tool passes over a material by pressing a spinning tool head with a pin against it. The heat from the friction, downward force, and rotating tool head creates pressure that welds the material together. This material is

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Vol 13, Issue.3 July 2025

simultaneously stirred by the pin, which causes it to mix.

In the Friction Stir Additive Manufacturing process, stacks of weld plates are first lap welded and then friction stir welded to form an object layer by layer. The Edison Welding Institute uses this technique.

Welding Parameters	Specimen 1	Specimen 2	Specimen 3	Specimen 4
Rotational Speed (Rpm)	900	900	1120	1120
Feed Rate (Mm/min)	25	40	25	40
Tilt angle (deg)	1	2	2	1

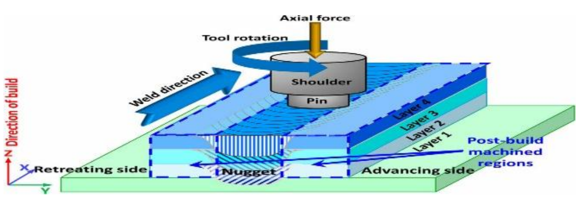

Figure : Friction Stir Additive Manufacturing

Steels, magnesium, copper, copper matrix materials, aluminium, and aluminium silicon carbide have all been successfully produced using FSAM.

METHODOLOGY: The experiments conducted to achieve the goals of this study on friction stir additive manufacturing using a tapered tool pin are detailed in this chapter. To determine how process parameters affected the joint properties, mechanical testing, including tensile, and micro hardness tests, was carried out in conjunction with microstructural characterization.

Welding strategy:

Work piece materials:

Commercially available aluminium alloy with a minimum of 99.00% aluminium content is called aluminium AA1100. It is renowned for its outstanding workability, high electrical and thermal conductivity, and resistance to corrosion. This qualifies it for use in thermal, chemical, electrical, and decorative applications.

Table : Chemical composition of aluminium 1100 by weight percentage

Elements of Al6061	Percentage %
Aluminium(Al)	99.0
Copper(Cu)	0.05-0.20
Iron(Fe)	0.0-0.95
Silicon(Si)	0.0-0.95
Zinc(Zn)	0.0-0.1
Manganese(Mn)	0.0-0.05

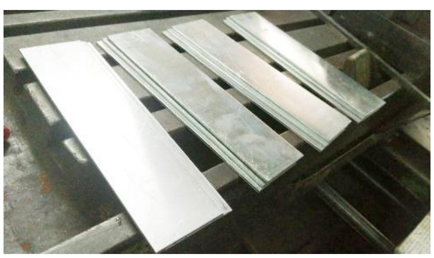

Figure : AA1100 Material

Tool Material :

H13 Steel

H13 steel is a chromium-molybdenum hot work tool steel that is frequently used in die and tooling applications because of its exceptional toughness, hardness, and resistance to thermal fatigue. With a 12% chromium content, it is a led eburitic chromium tool steel that provides remarkable wear resistance. Shear cutting edges, trimming dies, blanking dies for paper and plastics, rotary shear blades for sheet thicknesses up to 2 mm, and cutting tools for sheets up to 4 mm thick are the main applications for H13 steel.

Mechanical Properties (After Heat Treatment):

Property	Typical
Hardness	48–52
Tensile	~1,500
Yield	~1,300
Elongation	~13%
Impact	Good

Physical Properties:

Property	Value
Density	7.80
Thermal	24.6
Specific	460
Electrical	~0.65

FSW Tool Specifications:

Material	H13
Shank	18
Diameter	24mm
Shape of	Taper

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Vol 13, Issue.3 July 2025

Diameter	6-8
Length	5.8

Tool Material taken is H13:

- The tool shoulder diameter -24 mm,
- The length of the pin -5.8mm,
- Diameter of the taper tip of the tool-8 and 6 mm And Length of the tool – 65mm

Figure : FSW Tool

Friction stir welding:

In the current study, a vertical milling machine with an automated feed system was used to carry out the Friction Stir Additive Manufacturing process. This configuration guaranteed welding consistency and allowed for exact control over tool movement.

In order to achieve additive layers free of defects, the tool's rotational speed and feed rate (mm per min) were carefully chosen and optimized based on previous research and process requirements. A tapered pin tool profile was chosen for this project due to its ability to generate sufficient frictional heat and promote efficient plasticized material flow during the additive process.

The gradual reduction in pin diameter facilitates better stirring action, minimizes void formation, and enhances bonding between successive layers. The tool shoulder was designed to apply uniform downward pressure, which helped in consolidating the material and maintaining consistent layer height. The use of a tapered pin is particularly advantageous in FSAM applications as it improves material mixing, reduces tunnel defects, and contributes to improved mechanical properties in the final build. This setup and tool design were critical in successfully fabricating multi layered joints with good structural integrity.

Figure : Vertical Milling Machine used for FSAM

Wire EDM Cutting:

A non-traditional machining technique called wire EDM (Electrical Discharge Machining) uses electrical discharges, or sparks, to precisely cut hard metals and complex profiles. It is particularly helpful for machining materials like conductive ceramics, super alloys, and hardened steels that are challenging to machine using traditional techniques.

Figure : Specimens after Tensile Test

Tensile Test :

Testing Tensile strength is a key mechanical property that indicates a material's ability to withstand loads that tend to elongate it. This property is determined through a tensile test, where a prepared specimen is subjected to uniaxial tensile loading until failure.

S.NO	UTS(Mpa)	Yield strength(Mpa)
Sample 1	91.891	76.141
Sample 2	88.704	72.487
Sample 3	88.948	79.672
Sample 4	91.229	74.166

In this investigation, tensile testing was carried out using a computer-controlled BISS Universal Machine.

Figure : Specimens of Hardness Test

Hardness Test Result:

To determine the hardness of materials, particularly thin sections and small pieces, the Vickers hardness test is used. To create an indentation on the object being tested, it consists of a diamond indenter and a light load. The object's hardness value is derived from the depth of indentation.

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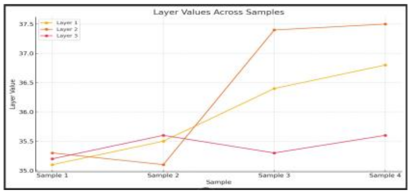
Vol 13, Issue.3 July 2025



Graph : Microhardness Test Report of Weld Specimens

The hardness of the specimen is calculated for every layer to evaluate the changes in the hardness due to temperature distribution in the weld specimen from the top layer to the bottom layer.

Sample 1: It has been noted that the weld specimen's hardness actually changes from layer to layer as a result of variations in the specimen's temperature distribution. As can be seen, the weld specimen's top layer has a hardness value of 35.1, followed by the second layer, which has a hardness value of 35.3, and the bottom and final layer, which has a hardness value of 35.2.

Sample 2: Similarly, the top layer of the weld on this specimen has a hardness value of 35.5, the second layer has a hardness value of 35.1, and the final layer has a hardness value of 35.6.

Sample 3: It has been noted that the weld specimen's hardness actually changes from layer to layer as a result of variations in the specimen's temperature distribution. It is evident that the top layer of the weld specimen has a hardness value of 36.4, followed by the second layer, which has a hardness value of 37.4, and the bottom and final layer, which has a hardness value of 35.3.

Sample 4: This specimen's hardness number is as follows: The specimen's top layer recorded a value of 36.8, middle layer recorded 37.5, and bottom layer recorded 35.6.

According to the aforementioned observations, the hardness of the welded specimens shows a slight variation in hardness number from layer to layer as the temperature distribution increases from the top layer to the bottom layer of the weld joint.

CONCLUSIONS: In order to thoroughly examine and improve the Friction Stir Additive Manufacturing (FSAM) process as it relates to AA1100 aluminium alloy plates, we used an experimental approach in this study. The main goal of our study was to evaluate how different process parameters affected important factors such the FSAM joint's impact strength, hardness, microstructure, and Ultimate

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Vol 13, Issue.3 July 2025

Tensile Strength (UTS), which are examined layer by layer. In this investigation observed that ultimate tensile strength (UTS) maximum at sample 1 as 91.891 mpa and yield strength was maximum at sample 3 as 79.672 mpa.

Future Scope of FSAM:

As additive friction stir manufacturing is still in its early stages of development.

One of the major scopes for FSAM is military industry vehicles production here the vehicles manufactured need to be sophisticated, strong and light in weight the FSAM can replace the joining of the metal sheets by rivets and this also reduce the weight and

Friction Stir Additive Manufacturing (FSAM) has promising potential for further research and industrial application. Future work can focus on:

- Optimizing process parameters and tool designs to improve mechanical properties and reduce defects.
- Expanding FSAM to multi-material and large-scale components for aerospace and

improves the quality.

Future Scope of FSAM:

- Optimizing process parameters and tool designs to improve mechanical properties and reduce defects.
- Expanding FSAM to multi-material and large-scale components for aerospace and automotive uses.
- Integrating real-time monitoring and AI-based control for better build quality.
- Studying detailed fatigue, corrosion, and microstructural behavior to develop industry standards.
- Improving sustainability by reducing energy use and material waste, making FSAM cost- effective for broader applications.

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Vol 13, Issue.3 July 2025

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