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# EXPERIMENTAL INVESTIGATIONS OF THERMAL PROFILES AND MICROSTRUCTURE EVOLUTION IN FRICTION STIR WELDING: A REVIEW

**Sumer Singh, Vishnu Agarwal**
**E-Mail Id: sumerrock1993@gmail.com**
**Department of Mechanical Engineering, GITS, Udaipur, Rajasthan, India**

**Abstract -** This work demonstrates the feasibility of friction stir welding (FSW) as a novel technique for joining aluminum sheets while analyzing thermal profiles and microstructural evolution. Defect-free welds were achieved on 1.6 mm thick plates at a welding speed of 160 mm/min and 450 rpm using die steel tools. Optical microscopy revealed distinct microstructural regions in the weld zone, while transverse microhardness measurements and tensile tests confirmed the welds' strength, with failure occurring outside the weld area. The study highlights the potential of FSW for aluminum welding, particularly in automotive applications where aluminum alloys of the 5XXX/6XXX series are increasingly used for tailor welded blanks (TWBs) due to their superior formability. Despite extensive research on process parameters and weld quality, experimental studies on thin-sheet AA 5XXX/6XXX TWBs remain limited, underlining the significance of this work.

**Keywords:** Friction Stir Welding (FSW), aluminum alloys, thermal profiles, microstructure evolution, microhardness, tensile strength, tailor welded blanks (TWBs), automotive applications.

## 1. INTRODUCTION

In current automotive stamping technology, there are two basic paths that can be followed to arrive at the final panel. The first method is part disintegration. In this technique, each different section of the blank is stamped separately and then spot welded together in the shape of the final part. This method has numerous advantages such as the ability to select specific properties, i.e. the strength, thickness, corrosion resistance etc of each area of the blanks. This method also gives a higher yield ratio of material used. However, this method has some disadvantages. The major problem is the large number of different forming operations that is required for the disintegration method, which translates to high tooling costs. Also, assembly costs would increase (more joining required) and there is possibility of fittability problem between the different stampings. The other possible method is the integration method. In the integration method, the part is stamped out of a single blank. This reduces the number of tools needed; the assembly's cost and eliminate the fittability problem. However, the design engineer is forced to work with the same grade, thickness, strength and corrosion resistance throughout the entire part; this would increase the cost and weight of the part significantly.

A solution to the problems listed above is the utilization of the tailor welded blanks. A tailor welded blank is the blank that is comprised of two separate pieces of sheet metal that has been welded together before stamping. Tailor welded blank allows the welding of different grades, different thickness, different strength and different corrosion coating together in order to give the properties needed in different areas, without increasing the number of tools needed to form the part and eliminating the fittability concerns. They also allow a high degree of flexibility in designing parts and large blanks can be formed into a much smaller sheet.

With the changing attitude of society towards the environment, the use of laser welded blanks could be very beneficial to the automotive industries. This includes reducing scrap from manufacturing and making their product more energy efficient. Along with the reduction of scrap, the automotive industry is subjected to more and more stringent government regulation for fuel efficiency. There is currently a large interest in developing lightweight alloys that can be used in an automobile to replace heavier steel parts, resulting in weight reductions of the vehicle without sacrificing strength. Metallic material such as aluminium and magnesium, high-strength steels, carbon-carbon composites as well as a number of novel metallic composites is all under investigation in terms of viability and practicality for use in high production in automobile.

A unique combination of properties puts aluminium and its alloys amongst our most versatile engineering and construction materials. All alloys are light in weight, yet some have strengths greater than that of structural steel. For automotive applications aluminium alloy sheets have the advantages of corrosion resistance, high strength to weight ratio, and recyclability.

Laser, electron beam, tungsten inert gas, metal inert gas and friction stir welding processes have been used for creating tailor welded blanks. However, due to the small heat effected zone (HAZ) and fusion zone, the laser and electron beam welding process produce less impact on material properties than others. Laser welding has been the most frequently used process for producing TWBs due to the lower cost and greater flexibility compared to those of electron beam welding. However, there are several difficulties to develop TWB

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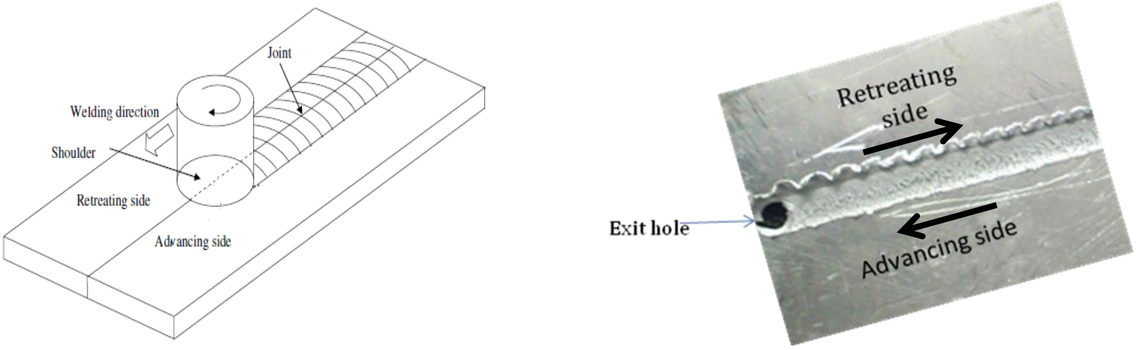
particularly for aluminum and magnesium alloys because of their high reflectivity, low molten viscosity and inherent oxide layer, conventional laser welding leads to hot cracking in the fusion zone and the poor coupling during welding process. Therefore, as a newly emerging welding technology for TWB, friction stir welding (FSW) was developed primarily for aluminum alloys. Friction stir welding was invented by Wayne Thomas at TWI (The Welding Institute), and the first patent applications were filed in the UK in December 1991. Initially, the process was regarded as a "laboratory" curiosity, but it soon became clear that FSW offers numerous benefits in the fabrication of Aluminum products.




(a) (b)

**Fig 1.1 (a) Schematic illustration of the Friction Stir Welding process [1] (b) An FSW weld between Aluminum Sheets**

Friction stir welding (FSW) is a solid–state, hot–shear joining process in which a rotating tool with a shoulder and a pin, moves along the butting surfaces of two rigidly clamped plates placed on a backing plate as shown in Fig. 1.1 The shoulder makes contact with the top surface of the work–piece. Heat generated by friction at the shoulder surface, softens the material being welded. Severe plastic deformation and flow of this plasticized metal occurs as the tool is translated along the welding direction. Material is transported from the front of the tool to the trailing edge where it is forged into a joint. Although Fig. 1.1 shows a butt joint for illustration, other types of joints such as lap joints and fillet joints can also be fabricated by FSW. The welding technology for tailor welded blank is well established. What is not understood is the forming characteristics of the TWBs. The problem is the prediction of how the process parameters will influence the weld quality and how the location of welds will influence the formability and their mechanical properties. In this project I will perform the friction stir welding process for producing tailor welded blanks and study the influence of process parameters on weld quality and perform formability test along with uniaxial tensile test and microhardness test.

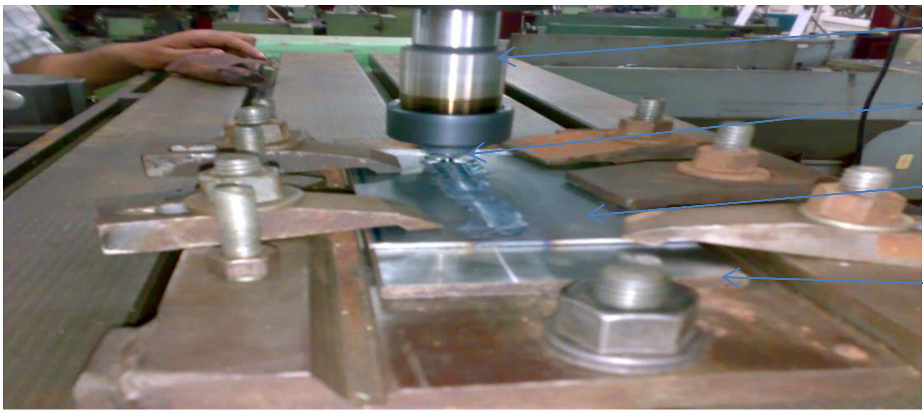
## 2. FRICTION STIR WELDING SETUP

The following were used for the Friction Stir Welding Process of Aluminium alloy sheets.

- Vertical Milling machine
- Fixture
- Backing Plate
- Tool
- Specimen

### 2.1 Fixture

A fixture is a work-holding or support device used in various manufacturing processes. The main purpose of a fixture is to locate and in some cases hold a workpiece during a machining operation.



Spinndlendal

Tool

Work Piece

Backing plate

**Fig. 2.1 Fixture used in FSW Process**

**2.2 Backing Plate**

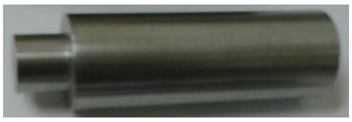
A plate of dimensions 200 x 100 x 10 mm was firstly cut by hacksaw machine then machined on shaper in order to reduce the thickness to 8 mm and later the finishing process was carried out on surface grinding machine. The flatness of the backing plate is a crucial factor in order to perform the experiment correctly.

**Fig. 2.2 Backing plate (200X100X8 mm) used in FSW Process**

**2.3 Tool**

A round bar of diameter 25 mm and length 75 mm of **EN31 [**is a high carbon alloy steel which achieves a high degree of hardness with compressive strength and abrasion resistance.] was machined on lathe to produce a tool. The final dimensions of the tool were

**Table 2.1: FSW tool dimensions.**

| Tool | Tool 1 | Tool 2 | Tool 3 |
|---|---|---|---|
| Tool Figure |  |  |  |
| Tool pin Diameter | 8 mm | 12 mm | 16 mm |
| Tool pin length | 10 mm | 10 mm | 10 mm |
| Shank Diameter | 19.95 mm | 19.95 mm | 19.95 mm |
| Shank length | 55 m | 55 Mm | 56 mm |

**2.4 Specimen**

Aluminium alloy sheets of thickness 1.7 mm were cut into strips of dimension 170 x 52 mm in shearing machine. Firstly, 30 strips of above dimensions were cut and later machined on shaper on the edge to be welded in order to get co-aligning of specimens.

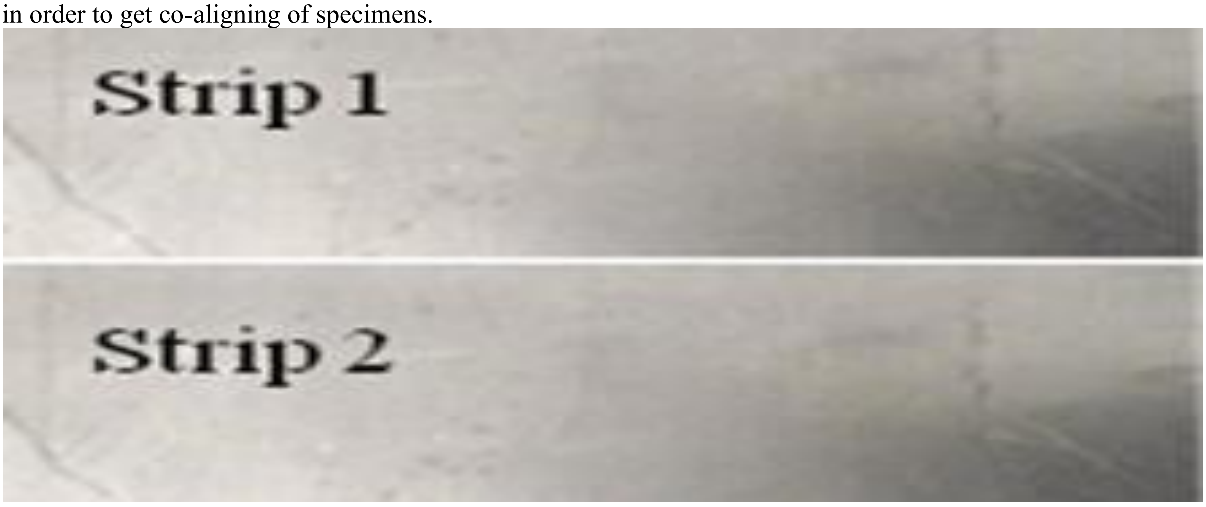


**Fig. 2.3 Specimen (170X50X1.7 mm)**

**2.5 Welding procedure**

In trail experiment four different speeds with constant shoulder diameter, weld speed and depth of plunging were selected for the study as shown in table 2.2. The rolling direction of the sheet was parallel with the welding. Prior to the welding, the edge of the strips was machined in shaper machine. Firstly, the finished edges of two specimens were brought into contact, and specimens were placed on the backing plate. Then they were clamped using fixtures as shown in figure 2.1. After welding the weld specimen given below in figure 2.4(a, b)

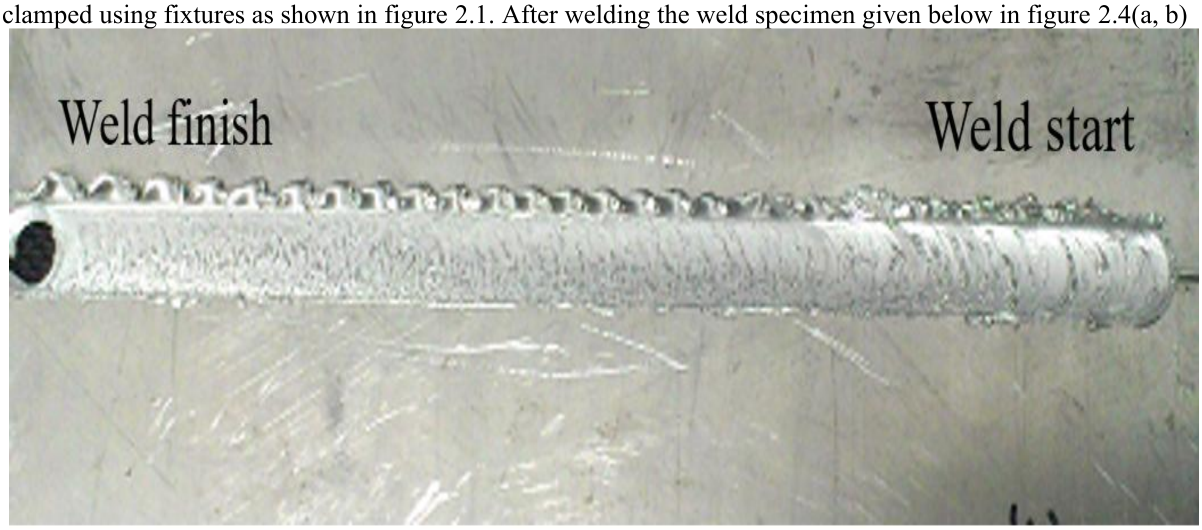



**Fig. 2.4 (a): Weld specimen [top view]**

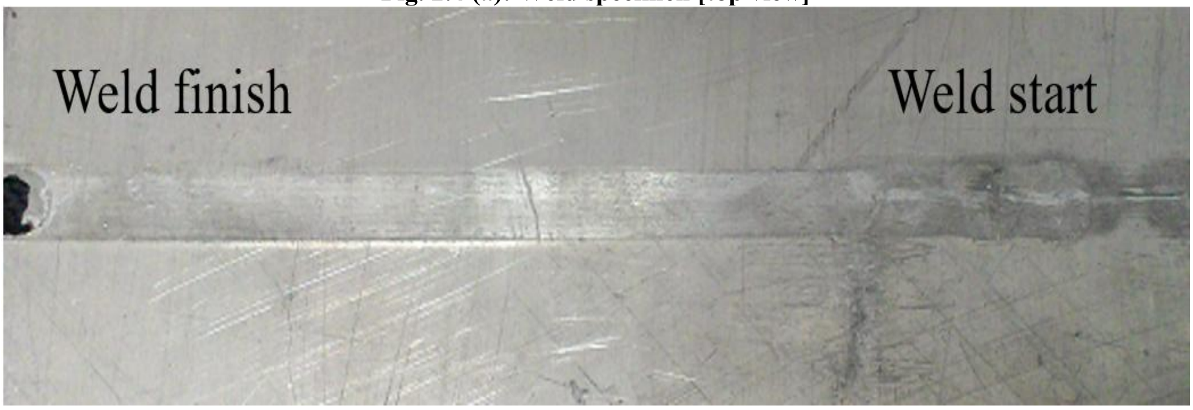



**Fig. 2.4 (b): Weld specimen [bottom view]**

**Table 2.2 Process parameters taken for trail experiment**

| Sample No. | Rotational speed (in rpm) | Shoulder diameter (in mm) | Welding feed (In mm/min.) | Depth of plunging (in mm) |
|---|---|---|---|---|
| 1 | 355 | 8 | 160 | 0.35 |
| 2 | 450 | 8 | 160 | 0.35 |
| 3 | 560 | 8 | 160 | 0.35 |
| 4 | 710 | 8 | 160 | 0.35 |

**2.6 Selection of Process Parameters**

The quality of FSW welds is greatly dependent on the selection of process parameters such as welding speed (mm/min), rotation speed (rpm) and tool diameter. Since the heat generation [eq. 2.1] in weld nugget zone plays an important role in determining the mechanical properties of the weld. Therefore, it is very important to select the welding process parameters for obtaining optimal heat in the weld nugget zone. In the welding was carried out by using the selected variations of parameters as shown in Table1 which is obtained by Taguchi's orthogonal array method. The Taguchi method involves reducing the variation in a process through robust design of experiments. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. Primarily visual inspection evaluates the good quality of welds obtained by FSW. Four welds were developed on each set of parameters.

**Table-2.3 Process parameters**

| Welding Run No. | Rotational speed (rpm) | Welding speed (mm/min) | Tool diameter (mm) | Depth of plunging (mm) | Result |
|---|---|---|---|---|---|
| 1 | 450 | 80 | 8 | 0.35 | Good |
| 2 | 450 | 160 | 12 | 0.35 | Poor/over heating |
| 3 | 450 | 250 | 16 | 0.35 | Not possible due to over heating |
| 4 | 560 | 160 | 8 | 0.35 | Good |
| 5 | 560 | 250 | 12 | 0.35 | Poor/ over heating |
| 6 | 560 | 80 | 16 | 0.35 | Not possible due to over heating |
| 7 | 710 | 250 | 8 | 0.35 | Good |

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