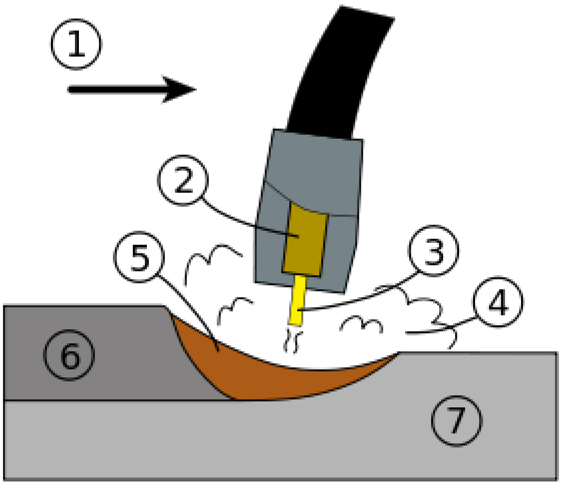
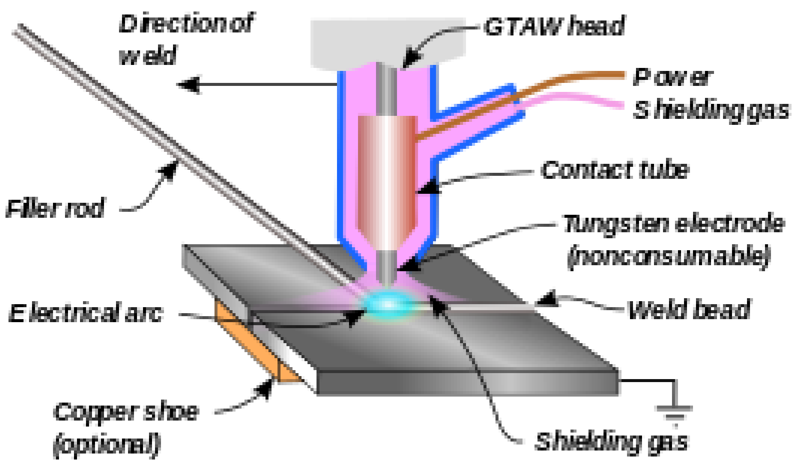
Introduction of welding :

- **Gas metal arc welding** (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) welding or metal active gas (MAG) welding, is a welding process in which an electric arc forms between a consumable wire electrode and the workpiece metal(s), which heats the workpiece metal(s), causing them to melt and join .



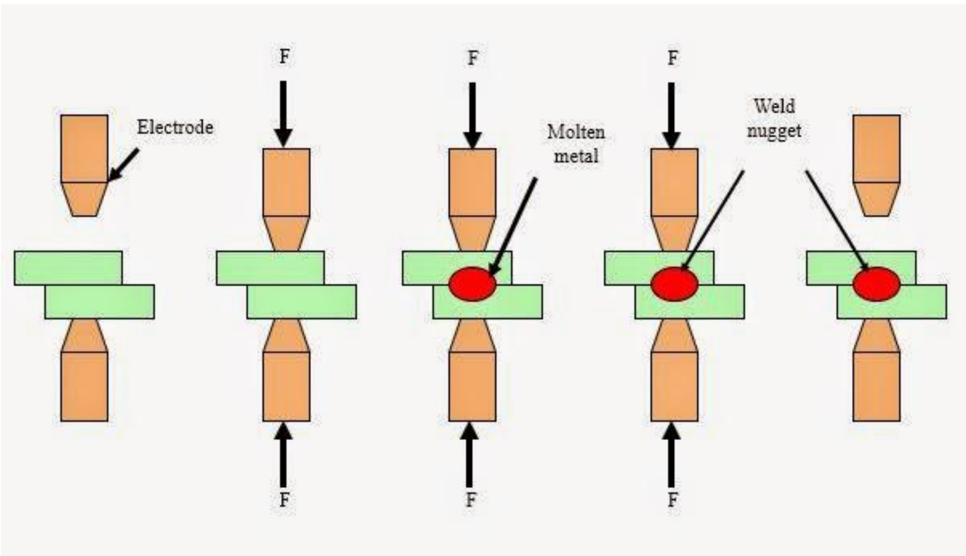
GMAW weld area. (1) Direction of travel, (2)Contact tube, (3) Electrode, (4) Shielding gas, (5)Molten weld metal, (6) Solidified weld metal, (7)Workpiece

- TIG : Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area and electrode is protected from oxidation or other atmospheric contamination by an inert shielding gas (argon or helium), and a filler metal is normally used



- **Stud welding :** Stud welding is a complete one-step fastening system, using fasteners called weld studs. Weld studs come in a variety of designs, threaded, unthreaded, tapped, etc., sizes and shapes for a wide range of applications.

- **Spot welding :** Resistance **spot welding** (RSW) is a process in which contacting metal surface points are joined by the heat obtained from resistance to electric current. It is a subset of electric resistance welding. .



- Friction Stir Welding (FSW), a solid state joining process invented by Thomas at TWI in December 1991. FSP, as well as FSW, does not involve exceeding the melting temperature of the metal that is to be processed.

Case study “ ALUMINUM ALLOYS AND WELDING OF ALUMINUM ALLOYS”

Aluminum is the most abundant metal available in the earths crust, steel was the most used metal in 19th century but Aluminium has become a strong competitor for steel in engineering applications after the 19th century. Aluminium has many attractive properties compared to steel it is economical and versatile to use that is the reason it is used a lot in the aerospace, automobile and other industries. The most attractive properties of aluminum and its alloys which make them suitable for a wide variety of applications are their light weight, appearance, fabricability, strength and corrosion resistance. The most important property of aluminum is its ability to change its properties in a very versatile manner; it is amazing how much the properties can change from the pure aluminum metal to its most complicate alloys. There are more then a couple of hundreds alloys of aluminum alloys and many are being modified form them internationally. Aluminium alloys have very low density compared with steel it has almost one thirds the density of steel. Properly treated alloys of aluminum can resist corrosion by water, salt and other factors, it can also resist the oxidation process which steel can not resist.

There are many different methods available for joining aluminum and its alloys. The selection of the method depends on many factors such as geometry and the material of the parts to be joined, required strength of the joint, permanent or dismountable joint, number of parts to be joined, the aesthetic appeal of the joint and the service conditions such as moisture, temperature, inert atmosphere and corrosion.

Welding is one of the most used methods for aluminum. Most alloys of aluminum are easily weldable. MIG and TIG are the welding processes which are used the most, but there are some problems associated with this welding process like porosity, lack of fusion due to oxide layers, incomplete penetration, cracks, inclusions and undercut, but they can be joined by other methods such as resistance welding, friction welding, stud welding and laser welding. When welding many physical and chemical changes occur such as oxide formation, dissolution of hydrogen in molten aluminum and lack of color change when heated.

The formation of oxides of aluminum is because of its strong affinity to oxygen, aluminum oxidizes very quickly after it has been exposed to oxygen. Aluminum oxide forms if the metal is joined using fusion welding processes, and aluminum oxide has a high melting point temperature than the metal and its alloys it self so it results in incomplete fusion if present when joined by fusion welding processes.

Weldability of aluminum alloys

Weldability of some aluminum alloys is an issue with the fusion welding processes such as metal inert gas welding (MIG), tungsten inert gas welding (TIG) etc . The 2000 series, 5000 series, 6000 series and 7000 series of aluminum alloys have different weldabilities. The 2000 series of aluminum alloys have poor weldability generally because of the cooper content which causes hot cracking and poor solidification microstructure and porosity in the fusion zone so the fusion welding processes are not very suitable for these alloys. The 5000 series of aluminum alloys with more than 3% of Mg content is susceptible to cracking due to stress concentration in corrosive environments, so high Mg alloys of 5000 series of aluminum should not be exposed to corrosive environments at high temperatures to avoid stress corrosion cracking. All the 6000 series of aluminum are readily weldable but are some times susceptible to hot cracking under certain conditions. The 7000 series of aluminum are both weldable and non-weldable depending on the chemical composition of the alloy. Alloys with low Zn-Mg and Cu content are readily weldable and they have the special ability of recovering the strength lost in the HAZ after some weeks of storage after the weld. Alloys with high Zn-Mg and Cu content have a high tendency to hot crack after welding. All the 7000 series of aluminum have the sensitivity to stress concentration cracking.

All these problems associated with the welding of these different alloys of aluminum has lead to the development of solid state welding processes like Friction Stir Welding technique which is an upgraded version of the friction welding processes. This process has many advantages associated with it, and it can weld many aluminum alloys such as 2000 and 7000 series which are difficult to weld by fusion welding processes, this can be shown in the figure(3-1). The advantages of the Friction Stir Welding processes are low distortion even in long welds, no fuse, no porosity, no spatter, low shrinkage, can operate in all positions, very energy efficient and excellent mechanical properties as proven by the fatigue, tension and bend tests.

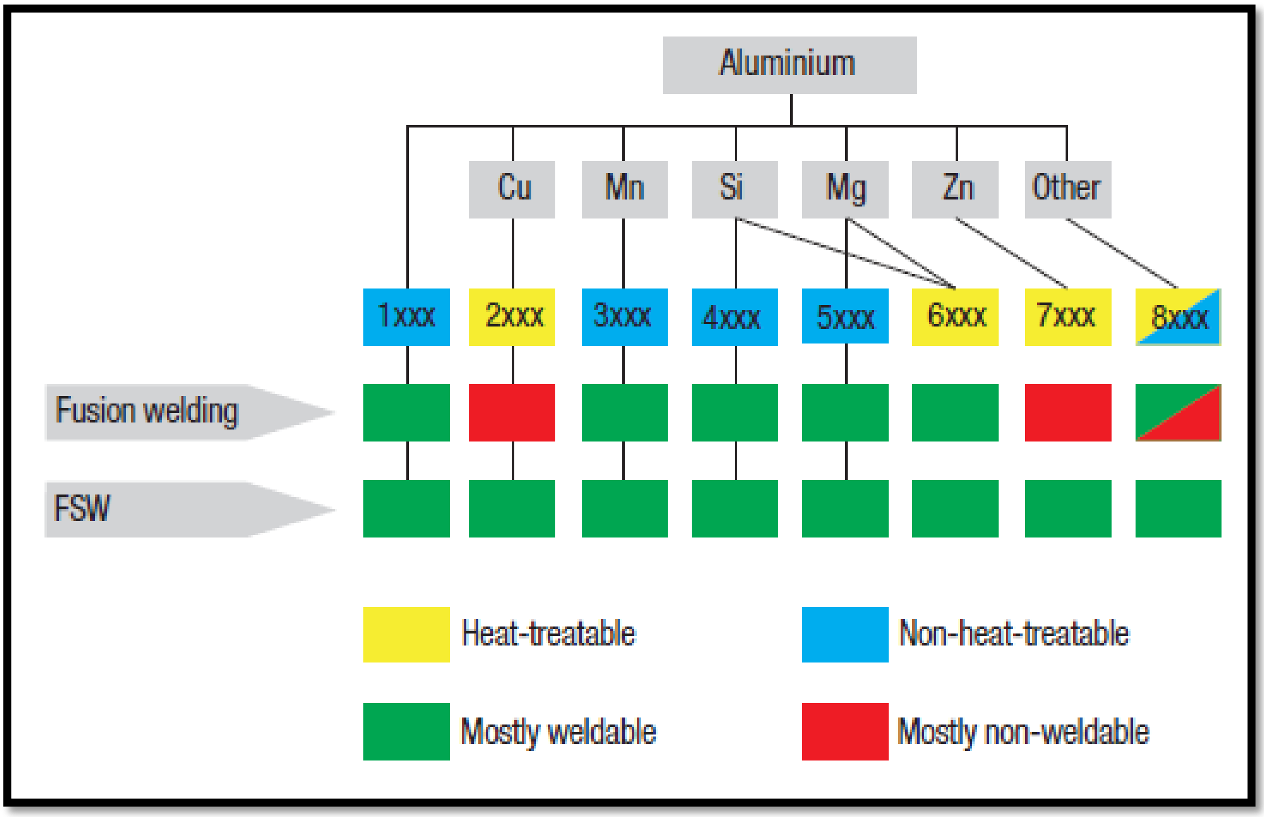


Fig.(2) Weldability of various aluminum alloys according to ASTM.

Classification

The classification of Al alloys can be categorized into two main groups; either as cast alloys or wrought alloys. Further to this, the alloys are usually subdivided into those that are heat treatable, or non-heat treatable. This property is mainly dependent on the presence of the alloying elements with high solid solubility in Al, and their ability to form fine second phase precipitates within the alloy. In general, heat treatable alloys tend to exhibit higher strength than non-heat treatable alloys. This is because precipitates within the microstructure can act as very effective barriers, blocking and hindering dislocation motion. Therefore, the greatest achievable strength and hardness of Al alloys are found in carefully heat treated conditions. However, these Al alloys tend to be less thermally stable at elevated temperature, because the precipitates can redissolve and return into solid solution, or coarsen, which will affect both the microstructure and properties of the alloy.

Al alloys are largely produced as wrought plates or sheets, which are used extensively in structural and aerospace applications, although certain alloys are widely used as casting. In order to further classify wrought Al alloys, an international designation system has now been adopted based on that introduced by the American Al association, shown in table (1) . Each wrought Al alloy is described using a 4 digit number, and with additional letters and numbers to represent the tempering condition. Note that the first digit is the most significant, since it classifies the major alloying elements. The other digits usually relate to the purity of the alloy or the concentration and presence of other additives.

Table 1 International designation system for Al wrought alloys.

Code	Major Alloying Element(s)	Properties
1xxx	Pure	
2xxx	Cu (Mg)	Heat Treatable
3xxx	Mn (Mg)	Non Heat Treatable
4xxx	Si	Non Heat Treatable
5xxx	Mg	Non Heat Treatable
6xxx	Si & Mg	Heat Treatable
7xxx	Mg & Zn (Cu)	Heat Treatable
8xxx	Other	

To classify the tempered condition of wrought Al alloys, a suffix, which follows the four digits number, is used to represent the treatment. In most cases, the condition of the alloy is represented by a letter and a number (table). The letter indicates the basic general treatment (i.e. F = as fabricated, O = annealed, H = cold worked, and T = age hardened), whilst the number indicates the specific treatment.

Table 2 Basic temper conditions of commercial wrought Al alloys.

Tempers	Description
T3	Solution heat treated, cold worked and then naturally aged
T4	Solution heat treated, and naturally aged
T5	Cooled from high temperature shaping, and then artificially aged
T6	Solution heat treated, and then artificially aged to peak hardness
T7	Solution heat treated, and then artificially over-aged
T8	Solution heat treated, cold worked , and then artificially aged

FRICTION STIR WELDING AND ITS APPLICATIONS

Friction stir welding process involve joining the materials by plasticizing and then eventually consolidating the material around the joint line of the weld. First the base metal pieces which have to be joined are held suitable clamping force so that the work pieces do not fly away while welding. A rotating steel pin pierces a hole in the joint line between the workpieces to a predetermined depth and moves forward in the direction of the weld as shown in Figure (2).

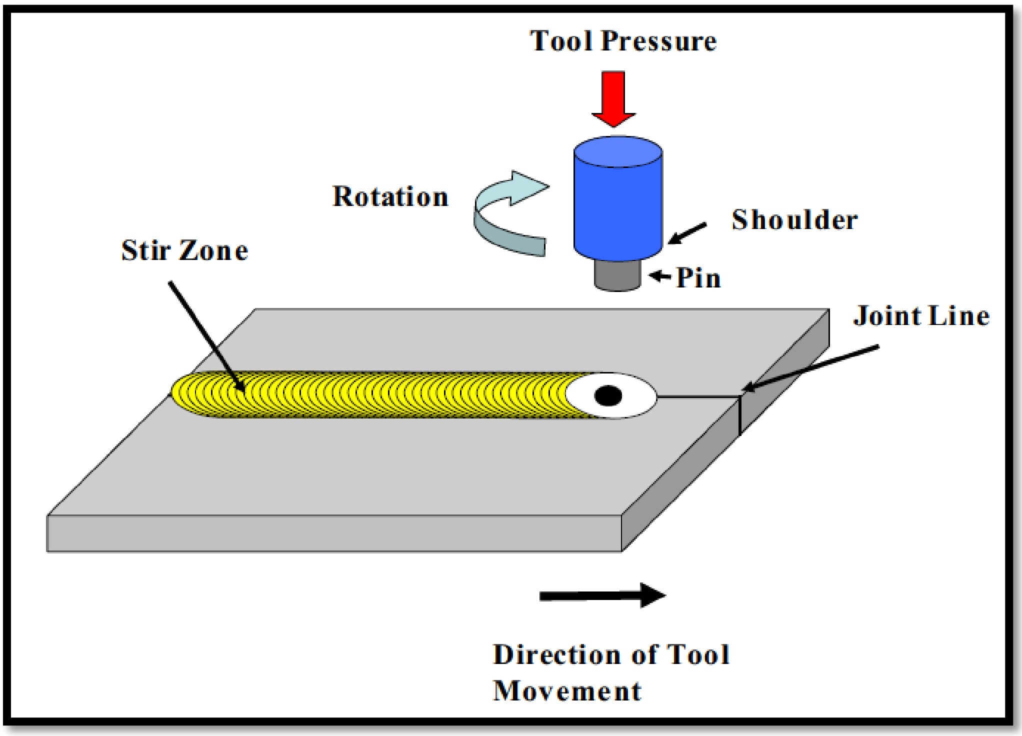


Fig Schematic of Friction Stir Welding process

As the pin moves forward it plasticizes the material due to the frictional heat generated by the rupture between the wear resistant steel pin and the workpiece. The force provided by the pin forces the plasticized material to the rare of the pin. This material cools and then consolidates to form a bond in the solid state of the material.

There is no melting and the weld is in hot worked condition with no much entrapped gases and porosity and the weld nugget has fine grained microstructure.

Advantages of friction stir welding

Friction welding is economical in that it permits joining together different materials,one of which may be inexpensive and its quality control cost is minimal with a gurantee of high quality welds. Moreover, the weld cycle is extremely short ,so that productivity is very attractive. Friction welding process is suitable for mass production.

The friction welding process is suitable for non-homogeneous joints involving materials having quite different chemical ,mechanical and thermal properties. The process is suitable for automation and adoptable for robot use. Other advantage as follows:[45D]

1- Weld heat affected zone (HAZ) has a fine grain hot-worked structure, not a cast structure found with conventional welding.

2- Material and machining cost savings.

3- 100% Bond of full cross section.

4- High production rates.

5-Automatic repeatability.

6- Stronger than parent material, with excellent fatigue resistance.

7- Similar and dissimilar material joined with no added fluxes or filler metals.

8- Low distortion, even in long welds.

9- Excellent mechanical properties as proven by fatigue, tensile, bend tests.

10- No fume is produced.

11- No porosity.

12- No spatter.

13- No filler wire is required for welding.

14- No welder certification is required.

15- Can operate in all positions.

16- More energy efficient than other welding technologies.

17- Environmentally friendly process minimizes energy consumption and generate no smoke, gasses or waste stream.

18- Joint strength equal or greater than that of parent material.

19- Join highly dissimilar metal combination to optimize your product's quality and properties.

20- Save labor, material and operations through near net size design.

21- Join less costly, lighter or tubular material to expensive material.

Disadvantages of friction stir welding

welding speed could be very slow for single pass welding techniques, the workpiece should be clamped very well with high clamping force in order to avoid accidents when the tool is plunged in between the plates to be welded and at the end of each weld there is a hole due to withdrawal of the pin from the plates. The hole due to the pin is filled by other welding processes in many cases for aesthetic purposes.[44D]

Also that not every configuration is feasible, that a machine of sufficient power is needed and that for short runs the process may not be economical.

Apart from the cost of equipment ,which must be suitable for the intended joints, the friction welding process has some costs in tooling and set up that must be taken into account when calculating the costs per weld. Tight cocentricity requirements, when needed, may be difficult to meet. Also finishing operations may be requested which sum up to the total cost.

Friction Stir Welding And Zones

FSW & FSP typically characterized as being comprised of three primary zones: the heat-affected zone (HAZ), the thermo mechanically affected zone (TMAZ), and the dynamically recrystallized zone (DXZ) or weld nugget as shown in Figure(3-4).

Fig.(5) Schematic of FSW & FSP primary zones

The heat–affected zone (HAZ) is similar to that in conventional welds although the maximum peak temperature is significantly less than the solidus temperature, and the heat–source is rather diffuse. This can lead to somewhat different microstructures when compared with fusion welding processes. The central nugget region containing the “onion ring” appearance is the one which experiences the most severe deformation, and is a consequence of the way in which a threaded tool deposits material from the front to the back of the weld. The thermo mechanically affected zone (TMAZ) lies between the HAZ and nugget; the grains of the original microstructure are retained in this region, but often in a deformed state.