A Review on Friction Stir Technology

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ABSTRACT

Friction stir technology is one of the severe plastic deformation technique used for enhancing mechanical properties of materials by grain refinement. The friction stir technology consist of Welding, processing and additive processing. Friction stir welding is one of the most efficient solid state joining process. It avoids many of the common problems of the fusion welding.
Friction Stir Processing (FSP) is an effective solid state surface modification technique used to locally eliminate casting defects, refine microstructure and improve the associated mechanical and physical properties including strength, ductility, fatigue, creep, formability and corrosion resistance. FSP is used to improve the surface properties of metals like aluminium, copper, brass and titanium.
Additive Friction Stir Processing can be used for coating, repair, manufacturing surface composites and additive manufacturing of similar or dissimilar materials. The process principle is simple and similar to friction stir welding/processing, with the exception of the use of filler material. The Filler materials is in the form of solid or powder is which undergoes severe plastic deformation, dynamic recrystallization, consolidation (if powder) and deposition. The properties of filler material is imparted to the original workpiece material.
Selection of tool material and tool design has huge influence over the tool performance, weld/process quality and cost. It affects the microstructure of the workpiece.
Various process parameters such as rotational speed, traverse speed, overlap percentage, filler material and filler amount are varied to get the best possible homogeneous grain structure for enhancing various properties of the material. This paper reviews friction stir technology and effect of process parameters on the microstructure and properties of the materials. Current scenario and future prospects, in this field, are also summarised.

Keywords*: FSW,FSP, AFSP, tool material, tool design*

1.INTRODUCTION:

Friction stir welding is a solid state joining technique and Friction stir processing is a surface modification technique were invented at The Welding Institute of UK in 1991[1]. The intrinsic nature of friction stir process has two basic components material flow and microstructural evolution. The progress of friction stir processing as metallurgical tool for microstructural modification and a broader manufacturing technology is connected to these. In friction stir processing super plasticity of material is important factor. Superplasticity is an ability of a material to exhibit >200 % elongation in tension. The most important microstructural features that govern the overall superplastic behavior are:
(a) fine grain size (<15 µm),
(b) equiaxed grain shape,

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(c) presence of very fine second phase particles to inhibit grain growth, and
(d) large fraction of high angle grain boundaries [2].

FSP comprises a rotating tool which is inserted in workpiece to modify the microstructure for specific property enhancement rather than joining the metals. The rotating tool consists of shoulder and pin. The pin is responsible for plastic deformation of the workpiece material, while shoulder is responsible for frictional deformation and temperature rise. The stirring action of pin generates fined grain microstructure. The friction stir process can be single or multi-pass as per requirement of the surface area of the plate to be modified [3].The localized heating make the material softer around the probe (Pin). The tool rotation and translation cause the movement of the material from the front to the back of the probe. The tool shoulder also restricts the metal flow under the bottom shoulder surface. Because of the various geometrical features of the tools, the material movement around the probe can be extremely complex and significantly different from one tool to the other. In FSP, as it is solid state processing technique, the work piece does not reach the melting point and the mechanical properties of the material are much higher compared to the traditional techniques. In fact, the undesirable microstructure resulting from melting and re-solidification, characterized by low mechanical properties, is absent leading to improved mechanical properties such as ductility and strength in some alloys [4]. Effect of process variables fall into three categories which are machine variables, tool design variables and material properties which is shown in Fig 2 [30]. Rotational speed and traverse speed determine the amount of heat input in the Stir Zone, which affects the microstructure and properties of material [31]. Lower the heat input more is the grain refinement and vice-versa, and there must be sufficient heat input to plasticize or soften the material, otherwise material will not be perfectly plasticized and we will unable to get good results.

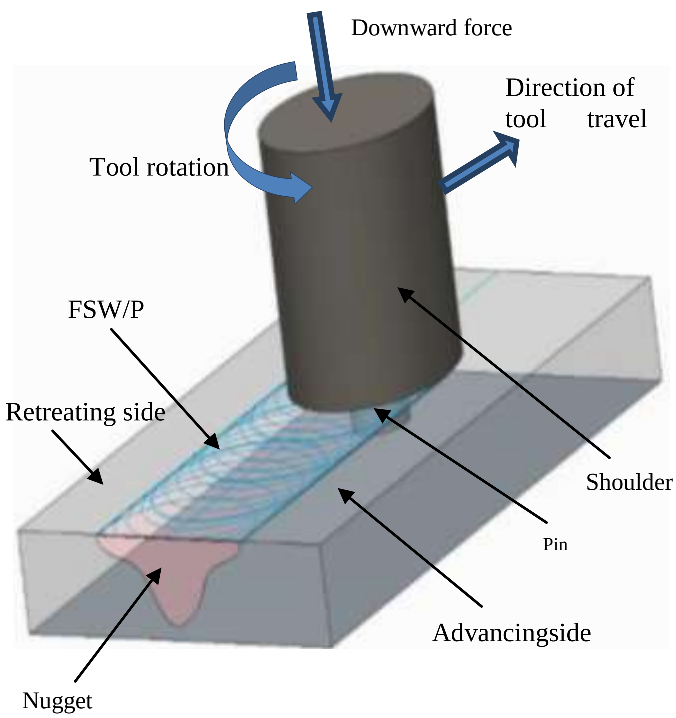

Fig.1: A schematic drawing of friction stir welding/processing

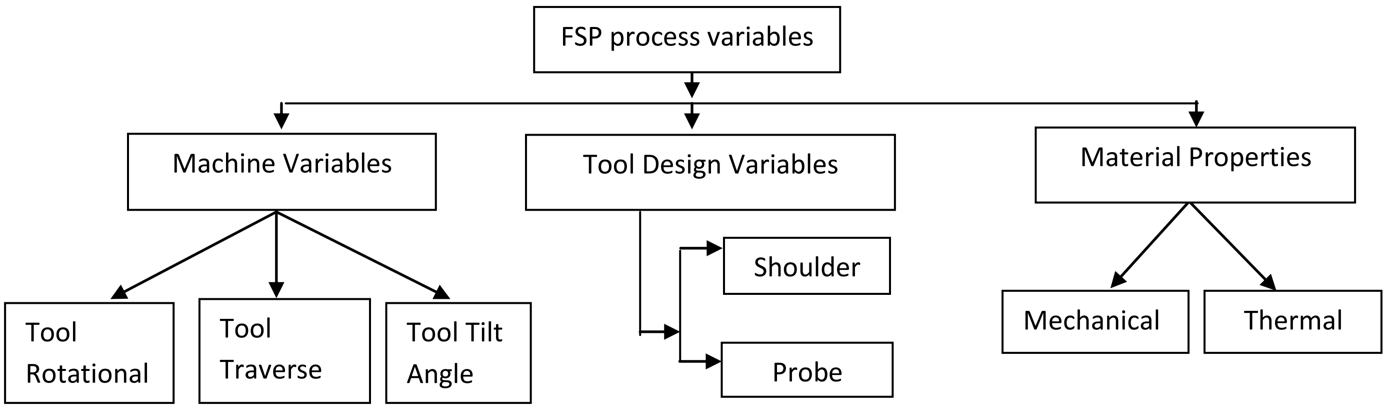

Fig 2: Classification of FSP process variables

2.Literature Review:

2.1.Brief review on tool material:

Selection of FSW and FSP tool material is a vital task which determines the quality of the weld formed. The tool material selection depends on the operational characteristics like operational temperature and axial force. Soft materials are welded easily using tool steels while harder materials need harder tool material for instance carbide based material and polycrystalline cubic boron nitride (PCBN). In the FSW of aluminium alloys, as aluminium is soft material, the wear of the tool is not as much. Hence, tool materials such as tool steels can be used. But, in the FSW of high melting point materials (steel, titanium) and two phase materials, such as metal matrix composites (MMCs), tool wear is a serious issue. Therefore tool material selection is considered to be one of the important tasks in FSW of steel, titanium and composites [5].

Properties of the material to be welded and also required quality of weld influence the tool material selection. The microstructure of the weld formed can be influenced by the interaction with the eroded tool material. The stresses induced in the tool depend on the strength of work material. Tool material properties influence the heat generation in the tool and hence the temperatures attained. As a result properties like thermal conductivity are important in tool material selection to achieve particular properties in the final joint. Thermal stresses which are experienced in the tool depend on the coefficient of thermal expansion. Tool material selection also depends on hardness, ductility and reactivity of the work materials [5].

1. The properties that have to be considered in choosing the tool material for FSW/P include;
2. Good strength, dimensional stability and creep resistance at ambient and elevated temperature,
3. Good thermal fatigue strength to resist repeated thermal cycles,
4. Good fracture toughness to resist the damage during plunging and dwelling,
5. Low coefficient of thermal expansion,
6. Good machinability for the manufacture of complex features on the shoulder and probe.
7. Resistance to wear
8. Chemical reactivity (It should cause harmful reactions with the weld metal) [6,7].

There are numerous tool materials that have been used in the FSW/P process. These materials include tool steels, Ni- alloys, high speed steel (HSS), metal carbides and ceramics. Table 1shows the tool material used for weld metals.

Tool Material	**Suitable material for weld**
Tool steel	Al alloys, aluminium matrix composites
Ni alloy	Copper alloys
WC-Co	Aluminium alloys, mild steel
WC composites	Aluminium alloys, low alloy steel, Ti- alloys
W-Re alloys	Aluminium alloys, Titanium alloys, mild steel

W alloys	Titanium alloys, stainless steel and copper alloys
PCBN	Copper alloys, stainless steels and nickel alloys

Table 1:Tool materials and suitable weld tool

2.2. Brief review of tool geometry:

There are basic three types of FSW and FSP tools which are fixed, adjustable and self-reacting. The fixed probe tool consists of a single piece comprising both the shoulder and probe. This tool can only weld a workpiece with a constant thickness due to the fixed probe length [8-10].

The adjustable tool consists of two independent pieces, i.e. separate shoulder and probe, to permit adjustment of the probe length during FSW. In this tool design, the shoulder and probe can be manufactured using different materials and the probe can be simply replaced when worn or damaged. Flexible probe length can permit welding of variable and multiple gauge thickness work pieces, and implementation of strategies for filling the exit hole, left at the end of the friction stir weld [11,12].

The bobbin or self reacting type tool is made up of three pieces: top shoulder, probe and bottom shoulder. This tool can weld multiple gauge thickness joints due to the variable probe length between the top and bottom shoulders [13-16].

2.2.1. Shoulder Shapes:

Tool shoulders are basically designed to generate frictional heat in the surface regions of workpiece and also produce the downward forging action which is essential to constrain the heated metal under the bottom shoulder surface.Three types of shoulder end surfaces are typically used, like flat shoulder, concave shoulder and convex shoulder. Of these, the flat shoulder end surface is the simplest design. The major disadvantage of this design is that the flat shoulder end surface is not effective for trapping the flowing metal material under the bottom shoulder [17].A concave shoulder end surface (6o-10o) has become popular for restricting material extrusion coming out from the sides of the shoulder [18]. Convex shoulder is another type of shoulder shape. The main advantage of the convex shoulder profile is that it can achieve contact with the workpiece at any location along the convex end surface, and hence, accommodate the differences in flatness or thickness between the two adjacent workpieces. Its major disadvantage is the inability of the smooth end surface to avoid material displacement away from probe causes weld integrity issues [19].

The shoulder end surfaces can also include some features to increase material friction, shear and deformation for increased workpiece mixing and higher weld quality [20,21]. The typical shoulder end styles include knurling, flat scrolls, ridges,, grooves and concentric circles, as revealed in Fig 3. These features can be applied to concave, flat or convex shoulder ends. Most used end feature is scrolls [13,22].

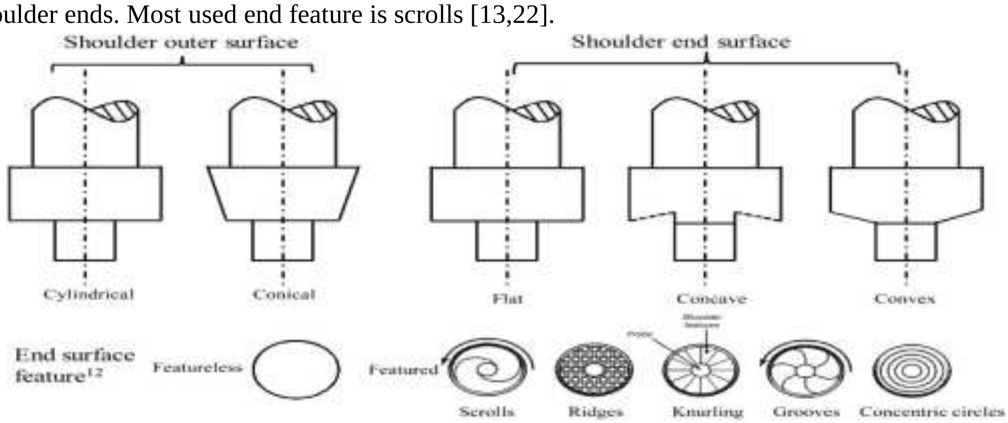

Fig 3: Shoulder Shapes and Features [5]

2.2.2. Probe shape:

The friction stirring probe is able to produce deformational and frictional heating. Ideally, it is designed to disrupt the contacting surfaces of the workpiece, shear the material in front of the tool and also move the material in the rear of the tool. The tool travel speed and depth of deformation are mainly governed by the probe. Fig. 4 shows the probe shapes and their main features. The end shape of the probe is either flat or it is domed. The major disadvantage of the flat probe is the high forge force during plunging. In contrast, a round or domed end shape can decrease the forge force and tool wear upon plunging, increase tool life by eliminating local stress concentration [23,24].

The FSW and FSP probes usually have a cylindrical outer surface but a tapered outer shape can also be used. In particular, cylindrical probes have been commonly used for joining plates. With the tapered probe, the higher frictional heat increases the plastic deformation due to the larger contact area of the probe with the workpiece. The probe outer surfaces can have various shapes and features including threads, flats or flutes. Threadless probes are chosen for highly abrasive alloys or high strength as the threaded features can be simply worn away [25]. Both Whorl and MXTriflute probes tools can weld at very high speeds, while achieving integral welds with good surface quality [26].

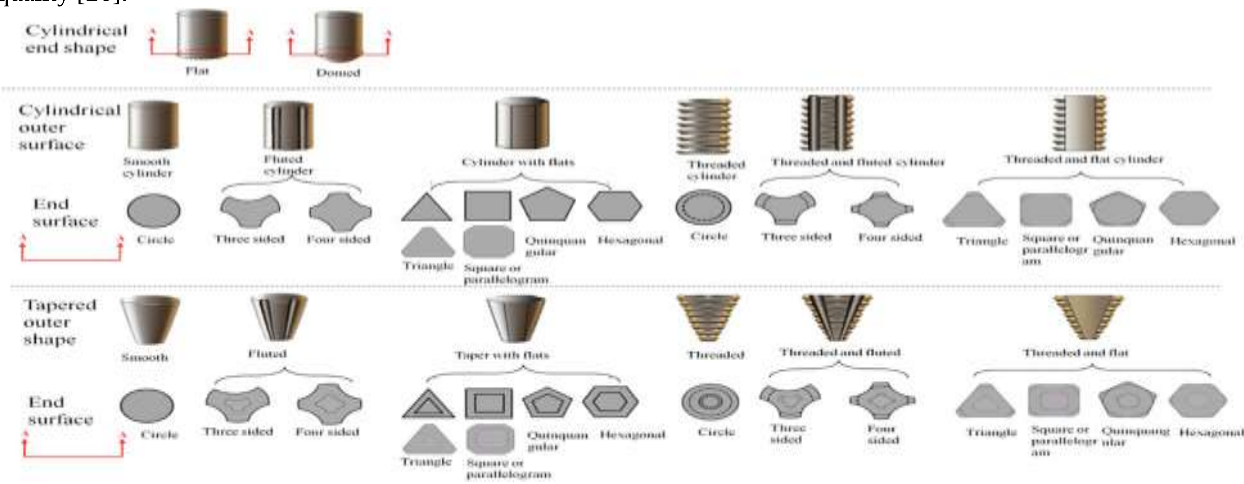

Fig 4: Probe Shapes[5]

2.3. Brief Review on Friction Stir Welding of Aluminium alloys-:

In Friction Stir Welding process, pressure and deformation provides a important portion of the bonding. No melting of base metal is necessary and filler material is not generally required. Diffusion bonding utilizes a pressure that is sufficient to locally deform the material. No gross deformation of the workpiece occurs [2]. In this method plates-to-be-welded clamped together rigidly in butt or overlap condition. The stirring tool with a suitable geometry moves along them.

Advantages of FSW are:-

1) 2XXX and 7XXX series Al alloys (Dissimilar) which are very difficult to join can be easily join by FSW.
2) As heat generated during welding is less, so there is no loss of mechanical properties.
3) Shrinkage, distortion and residual stresses are small; therefore thin plates can be successfully joined.
4) Because it is a solid state welding, problems encounter in conventional fusion welding methods such as porosity and cracking formation are not experienced.
5) Highly energy efficient.
6) Tool is non-consumable.
7) It is environmental friendly process.
8) There is no need of filler material.
9) It is suitable for automation and robotic applications. [5, 27]

Disadvantages of FSW are :-

1) It cannot be applied to every material. It can only be applied to material with low strength and low melting point. For welding of high melting point materials special tool is required.
2) The plates to be welded have to be fixed firmly.
3) The speed of Welding is relatively low.
4) Powerful machines are needed for joining thicker plates. [5, 27]

2.4 Brief Review on Friction Stir Processing (FSP):

A new processing technique called FSP was developed by Mishra et al., which works on the same principle of FSW, for microstructural modification and fabrication of metal matrix composites [28]. During FSP, a rotational tool pin (non-consumable) is plunged into the plate to be processed and traverses along the line of the plate. The FSP causes intense plastic deformation, material mixing and also thermal exposure resulting in significant microstructural refinement, densification, and homogeneity of processed zone. It has great advantages like, solid state microstructural evaluation, adjusting mechanical properties with the help of optimizing tool design and process parameters, control over depth of processed zone and location. [29].

Friction stir processed samples have been composed of three different zones named as Nugget Zone or Stir Zone, Thermo Mechanical Affected Zone and Heat Affected Zone. Nugget zone includes fine and recrystallized grain structure mostly due to simple plastic deformation and dynamic recrystallization [36,37].

Aluminum and its alloys are used regularly in fabrication of aerospace and transportation machine because of their noble things such as high strength to weight ratio and low density. The properties of aluminium and its alloys which is strength, elastic modulus, and resistance to wear; can be improved with corporation of ceramic particle into aluminium matrix (MMC) [38,39]. Moreover this process is used as an enhanced super plasticity method, homogenization of nano phase aluminium alloys and microstructural refinement of cast aluminium alloys.

2.5 Brief Review on Additive Friction Stir Processing-:

AFSP is a solid-state thermo-mechanical process for manufacturing of metal matrix composites used for a variety applications. Due to its additive nature, AFSP can be used for coating, repair, or additive manufacturing of similar or dissimilar materials. The process principle is simple and similar to friction stir welding/processing, with the exclusion of the use of filler material. Filler materials in the form of solid or powder is fed and deposited on upper layer of material up to certain depth using rotating tool. The filler metal is forced to flow between the rotating AFSP tool and the upper layer of material, whereby it undergoes severe plastic deformation, dynamic recrystallization, consolidation, and deposition. Desired properties can be obtained on upper layer of base material by adding different filler materials.

The addition of carbon nanotubes into various materials as a reinforcing fibre is a topic of interest nowadays. In addition to good chemical and thermal stability, CNTs demonstrate high yield strength and elastic modulus values [47-52].For example, single walled and multi-walled carbon nanotubes have elastic modulus of up to 1 TPa, and a yield strengths as high as 50 GPa[48,51]. As a result, these materials offer great potential as a reinforcing in composite materials. Some success has already been achieved in linking CNTs into polymer and ceramic matrices[49], and a few studies have focused on the preparation of metal matrix composites reinforced with Carbon nanotubes[53-56].

Additive friction stir processing of Al alloy (7075) by using silicon carbide nanoparticles to enhance the properties of alloy is successfully done by Mohsen Bahramiet al. In this study, SiCnano-particles were injected into the joint line of 7075 aluminium alloy. Subsequently, FSW was conducted at 1250 rpm and 40mm/min. Besides, the same experiment was carried out without using SiC particles to find the effects of SiC reinforcements on mechanical properties of the joint. Due to SiC nanoparticles UTS, percent elongation, toughness and fatigue life is increased [57].The presence of minor Sc and Zr produces, in Al Alloys, a strong increase in strength, ductility and Fatigue life [58]. This is due to the formation of very fine disperse Al(Sc, Zr)3 particles acting as grain boundary pinners and then as grain structure stabilizers up to very high temperatures[59].

3. CONCLUSION

In this study it can be concluded that

1. Tool material properties such as strength, fracture toughness, hardness, thermal conductivity and thermal expansion coefficient affect the weld quality, tool wear and performance.
2. The FSP leads to homogeneous microstructurealong with equiaxed and fine recrystallized grains whichcan affect the precipitation phenomenon.
3. The FSW of dissimilar, light-weight systems such as Al-alloysto Mg-alloys is encouraging for a host of aerospace and automotive applications
4. In AFSP the effect of the reinforcing particle type and FSPpasses on the microstructure, micro hardness, tensile strengthand wear properties of the fabricated surface composite layer.

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