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FRICTION STIR WELDING OF ALUMINIUM METAL MATRIX COMPOSITES-A REVIEW

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ABSTRACT
Friction stir welding is a patented new welding process that has led to many world wide applications, predominantly in the fabrication of aluminium components & panels. The application of this solid state welding technique to particles reinforced composites seems very attractive since it eliminate some typical defects induced by the traditional fusion welding techniques. This process for joining aluminium alloys is employed in aerospace, rail, automotive and marine industries. The FSW process parameters such as, the tool rotational speed, welding speed and the axial force play a major role in deciding the weld quality. Today impact test shows that total impact energy increased in FSW composites, respects to the corresponding base material. This review paper provides an overall view of FSW. This review concludes with the recommendation of future research directions.

INTRODUCTION
Friction Stir Welding (FSW) is a relatively nascent solid state joining technique developed at The Welding Institute (TWI) in 1991.Advanced materials like aluminum matrix composites (AMCs) have attracted considerable attention due to their appealing mechanical properties and a clear potential for aerospace applications, Reinforcements. FSW is a solid-state joining technique that has grown rapidly in popularity in a wide variety of industries including the aerospace, railway, land transportation, and marine industries. Several studies have been recently focused on friction stir welding of aluminum alloys and some data are also reported FSW of aluminum-based composites. The application of this solid state welding technique to particles reinforced composites seems very attractive, since it should eliminate some typical defects induced by the traditional fusion welding techniques, such as: gas occlusion, undelivered interfacial chemical reactions between the reinforcement and the molten matrix alloy, inhomogeneous reinforcement distribution after welding [2]. This process was first used at NASA.

Most often used on low melting point alloy s such as aluminum, FSW has many advantages over fusion welding techniques. Because process temperatures remain below the melting point of the welded material there is no need for either shielding gas or filler material; low distortion and low residual stresses are inherent to the process FSW is also an energy efficient process that no fumes, arc flash, or spatter. Perhaps the most significant advantage of FSW is that the technique allows for the joining of dissimilar materials or materials that are nearly impossible to fusion weld. It is Important to avoid overheating since the temperature must be maintained to be below the solidus of the equilibrium phase diagram for the materials being joined.[3] The main advantage is its ability to join metals without melting precludes the risk of traditional defects found in fusion welds such as liquidation cracking, solidification cracking, or oxide formation.

The FSW process includes three phenomena: heating, plastic deformation and forging. Non-consumable rotating tool, consisting of a probe and shoulder is plunged into the materials to be then traverses the joint line. Heat is generated through both friction and plastic deformation of welded material. The purpose of the review is to study the friction stir welding process on mechanical and microstructural properties of Aluminum alloy [4].

PRINCIPLE OF FRICTION STIR WELDING
A rotating cylindrical tool with a profiled probe is fed into a butt joint between two clamped work pieces, until the shoulder, which has a larger diameter than the pm, touches the surface of the work pieces. The probe is slightly shorter than the weld depth required, with the tool shoulder tiding at top of the work surface. After a short dwell time, the tool is moved forward along the joint line at the preset welding speed.

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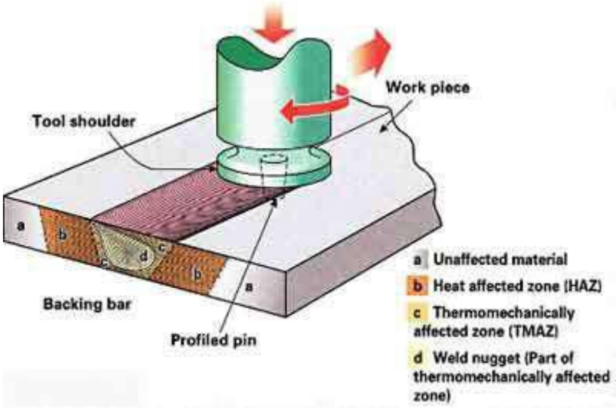
Frictional heat is generated between the wear-resistant tool and the work pieces. This heat, along with that generated by the mechanical mixing process and the adiabatic heat within the material causes the stirred materials to soften without melting. As the tool is moved forward, a special profile on the probe forces plasticized material from the leading face to the rear, where the high forces assist in a forged consolidation of the weld [5].

This process of the tool traversing along the weld line in a plasticized tubular shaft of metal results in severe solid state deformation involving dynamic recrystallization of the base material.

FRICTION STIR, WELDING PROCESS

The FSW process includes three phenomena: heating, plastic deformation, and forging. A non-consumable rotating tool, consisting of a probe and shoulder, is plunged into the materials to be joined and then traverses the joint line. Heat is generated both friction and plastic deformation of the welded material. Elevated temperatures, the material plasticizes and is sheared at the front of the probe and it is rotated to the rear of the probe where it is forged together under significant shoulder pressure. The FSW process is illustrated in Figure. The advancing side is the region in which the traverse velocity and the tangential velocity of the rotating tool are in the same direction. The retreating side is the region in which the traverse velocity and the tangential velocity of the rotating tool are in opposite directions. This advancing or retreating phenomenon leads to different mixing characteristics within the weld seam, depending on location.



Friction stir welding principle and microstructure

The material flow of the FSW uses a non-consumable tool to generate frictional heat at the point of welding, inducing gross plastic deformation of the work piece, resulting into a complex mix across the joint. The plates to be joined are placed on a rigid backing plate and clamped in a manner that prevents the abutting joint faces from separating. A cylindrical-shouldered tool, with a specially projecting pin (probe) with a screw thread, is rotated and slowly plunged into the joint line. The pin length is similar to the required weld depth. The development of the FSW machine will be made possible by converting a conventional milling machine into an adequate, functional, workstation where experimental.

Friction stir welded joints may be on various base materials.[6] Friction stir welding is a solid state joining technique, which has made possible the welding of a number of materials that were previously extremely difficult to weld reliably without voids, cracking or distortion. The method was derived from conventional friction welding. The shoulder of the tool is forced against the plate. The rotating tool causes friction heating of the plates which in turn lowers their mechanical strength. The threads on the pin assist in ensuring 'that plastically deformed material flows around the pin as the tool advances along the joint line. As the tool proceeds along the joint line, frictional heating is maintained ahead of the tool ensuring the required plastic state [7]. It subsequently stirs and recombines the plasticized material to the side of the tool where the material cools to form a solid state weld. At the end of the weld, the tool is retracted from the plate and leaves a hole at the end of the weld.

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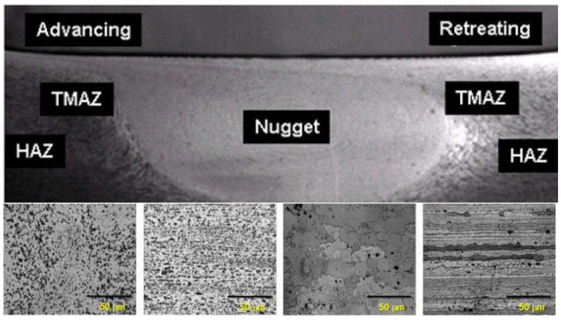
MICRO STRUCTURE ASPECTS

The solid-state nature of the FSW process, combined with its unusual tool shape and a symmetric speed profile, results in a highly characteristic microstructure.



micrograph showing various micro-structural zones

UNAFFECTED MATERIAL OR PARENT METAL

This is the material remote from the weld, which is not deformed and which, may have a thermal cycle from the weld, is not affected by the heat in terms of microstructure or mechanical properties [8].

HEAT AFFECTED ZONE (HAZ)

The material in this region lies close to the weld center and experiences a thermal cycle used for modifying the micro-structure and or mechanical properties. However, there is no plastic deformation occurring in this area. In the previous system, this was referred to as the

"Thermally affected zone". The term heat affected zone is now preferred, as this is a direct parallel with the heat affected zone in other thermal processes, and there is little justification for a separate name.
THERMO MECHANICALLY EFFECTED ZONE (TMAZ)

In this region, the material has been plastically deformed by the friction stir welding tool, and the heat from the process exerted some Influence on the material. In the case of aluminum, it is possible to get significant plastic strain without recrystallization and there is a distinct boundary between the recrystallised zone and the deformed zones of the TMAZ. In the earlier classification, these two subzones were treated as distinct microstructural regions.[8] However, subsequent work on other materials has shown that aluminum behaves in a different manner to most other materials, in that it can be extensively deformed at high temperature without recrystallization In 0ther materials, the distinct recrystallised region (the nugget)is absent, and the whole of the TMAZ appears to be recrystallised. This is certainly true of materials pure titanium, titanium alloys; austenitic stainless steels and copper, which have no thermally induced phase transformation, but induce recrystallization without strain. In materials such as ferrite steels and titanium alloys (e.g.T1-6A14V), the understanding of the microstructure is made more difficult by the thermally induced phase transformation, this also make the HAZ/TMAZ boundary difficult to identify precisely.[9]

WELD NUGGET

The recrystallised area in the TMAZ in aluminum alloys has traditionally been called the nugget. Although this term is descriptive, it is not very scientific. However, its use has become widespread, and as there is no word, which is equally simple with greater scientific merit, this term has been adopted. It has been suggested that the area immediately below the tool shoulder (which is clearly part of the TMAZ) should be given a separate category, as the grain structure is often different here. [10].The microstructure here is determined by rubbing by the rear face of the shoulder, and the material may have cooled below its maximum. It is suggested that this area is treated as a separate subzone of the TMAZ

MECHANICAL PROPERTIES OF FSW JOINTS IN AMCS

For FSW of AMC joints, the evaluation of mechanical properties including tensile strength, and fatigue is of considerable importance for components. It is also possible to optimize the welding parameters based on the evaluation of these properties which reflect the joint efficiency (the ratio of the tensile strength of joint to the tensile strength of base metal) of the weldment.

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Micro Hardness Of Amc Joints

Transverse micro hardness through the cross section of a welded joint can an indication about the Change of various phases reinforcement and distribution in FSW of AMCs, Two different profiles of micro hardness curves have been observed in the joint cross section of AMC weldment .Firstly, it is well accepted that the highest hardness value occurs in the centre of the NZ followed by a gradual decrease across the TMAZ and HAZ until reaching the hardness value .This is attributed to more gain refinement in the NZ due to dynamic recrystallization and more uniform distribution of finer reinforcement particles in the weld zone due to FSW action. These conclusions agreed in the Hall-Petch equation (Inversely proportional relation between hardness and grain Size) and the Orowan hardening mechanism (hardness can be improved if finer particles distribute homogenously).

Tensile Strength Of Amc Joints

The tensile strength of AMC joints fabricated by FSW was compared to that of the BM. The efficiency of joint produced by FSW is higher than that fabricated by conventional welding methods. Many factors influence the tensile strength of AMC joint including tool design, welding parameters and the formation of inter-metallic compound.

Fatigue Of Amc

Although many of AMC joints by FSW are to subject to dynamic there were few studies related to the fatigue of AMC joints [11].

The fatigue life of FSW joints is lower than the BM under all condition. This is attributed to the factors such as the modification of welded surface, joint microstructure, and higher amount of plastic strain induced by FSW. The roughness of the surface affects significantly the fatigue life when the strain amplitude decreases-Also the isotropic hardening value under low strain amplitudes. At strain amplitudes, the hysteresis loop area does not change. More over more plastic strain happened in FSW joints than in the BM in low cycle fatigue due to progressive hardening.

COMPARISON WITH OTHER PROCESSES

Growth of stir welding will be largely at the expense of other joining processes. In some areas, for example airframe manufacture, the indigenous process (mechanical fastening) is slow and expensive, and so the opportunity to replace it with a mechanized process, which can give results in high strength alloys, is attractive. In this case, friction stir welding is particularly relevant, as many high strength aerospace alloys are difficult to weld by fusion processes. However, in other industries, replacement of MIG and TIG welding by friction stir welding will never be complete, as these processes offer capabilities with which friction stir welding cannot compete. MIG and TIG welding have the advantage of using a filler (required in MIG, optional in TIG), and this allows the fabrication of joint designs where additional metal deposition is essential, for example in fillet welds, and in butt welds where the fit-up is variable or difficult to control.[3] Thus, in many applications (shipyards, railcars), long straight 6xxx extrusion are welded very economically by friction stir welding (where the absence of a filler in FSW is a distinct advantage) but- other attachments, E.g. bulkheads, stiffeners, closing welds, etc., are made by MIG welding. Similarly longitudinal welds in large tanks are easy to fabricate using friction stir welding, but the dome ends are generally more easily welded by fusion processes as this remove the need for Internal support to react the process forces. A future prospect for FSW is therefore an optimized integration of complementary welding processes.

Although FSW can be adapted to make the closure welds& the technology for this has lagged that required for the longitudinal welds. Another major asset of MIG and TIG is that these can be manual processes, and therefore offer improved flexibility, especially when dealing with variable fit-up, difficult access, etc. Although there is a risk of more variability in the quality than with mechanized welds.

Another factor is that the process can be taken to work whereas in friction stir welding the process at present has virtually no portability. Although some progress has been made in transportable rather than portable friction stir welding equipment, this area that is not yet well developed, although a successful development would open up numerous markets for the process [4].

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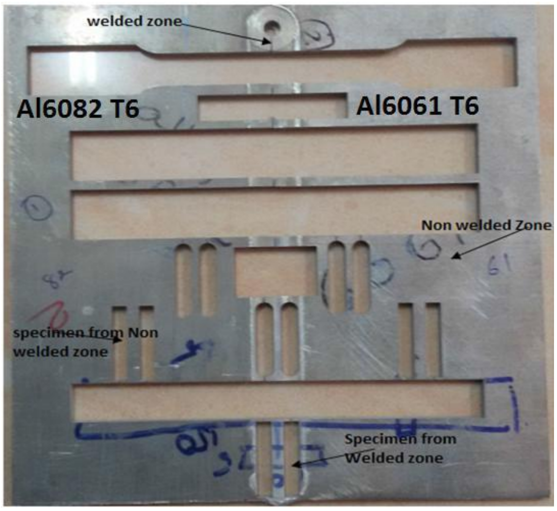
Friction Stir welding machine

WEAR TESTING

Wear Testing specimens we had taken the weld plates after NDT and considered the samples for wear testing, from welded and non-welded zones of dimensions[height=30mm, width=5mm, thickness=5mm] by using Wire EDM. Six (6) samples were taken from each [AA6061-AA6061],[AA6082-AA6082] and [AA6082-AA6061]

Two samples from welded zone and four samples from non welded zones as shown in figures.



Specimens

EXPERIMENTAL PROCEDURE FOR WEAR TEST

Pin-on disk machine (model TR 20, Ducom, India) is used to perform the drive sliding wear test as per ASTM G 99 standard ll. The stationary pin is aluminum alloys of different samples taken from non-welded zones and welded zones, and hardened die steel with Rc65 hardness is the rotating disk of the machine. The dimensions of the disc and specimen are shown in Figure. Under dry sliding conditions, Wear tests were performed with

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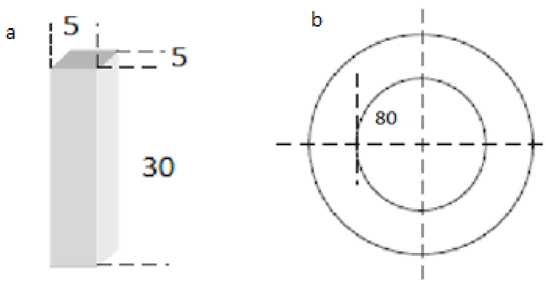
normal weight. In order to monitor and record the wear, frictional force and coefficient of friction continuously WINDCOM 2013 software was used for each test. They have conducted experiment using wear testing machine and the procedure for doing the wear test is explained here. Switch on the computer, control unit and Machine. Rotate the disks to RPM and set the speed by adjusting the RPM node. [13] Give support under the cantilever arm under unloading condition and arrest the arm without any movement. Based on the specimen dimension we can set the die and fix the work piece properly.App1y the load according to the requirement and remove the support under the arm. They had two knobs, adjusting knobs and thumb knob, release the two knobs freely and check the values on the control unit. Now adjust the thumb knob to the value of wear and the frictional factor to zero on control unit and then fix the thumb knob and set the required time by pressing the timing buttons. Open the Windcom icon from the desktop and give the input parameters (like file name, specimen dimensions, load, tack diameter and time) On the Wind com software file. Now press the start button in the software as well as in the machine control unit simultaneously as shown m Figures. After the test is completed for the required time taken, the values and graphs of wear rate, friction factor are noted from the software and control unit simultaneously.

1kg load at 65mm wear track diameter

Sample	**Applied load (kg)**	**Time (min)**	**Speed (rpm)**	**Track dia-meter (mm)**
i -6061/6082				
6061 W	1	5	640	65
6082 W	1	5	640	65
6061 NW	1	5	640	65
6082 NW	1	5	640	65
II- 6061/6061				
6061 NW	1	5	640	65
6061 W	1	5	640	65
III-6082/6082				
6082 NW	1	5	640	65
6082 W	1	5	640	65



Upper Pin Specimen

Lower Disc Specimen

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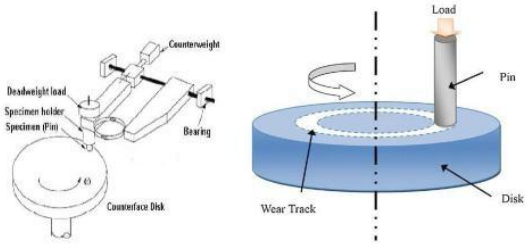

Test procedure

SUMMARY

It is hoped that the above thoughts give a reasonable summary of the state of the art for friction stir welding used in AMC's, and for its future. It is expected with reasonable certainty that the process will continue to grow, and the applications will increase, but the extent of this is impossible to forecast. However, these thoughts are based only on past experience, and history has shown many examples where attempting to predict the future by extrapolation of the past are a dangerous activity.

The technology is not yet fully matured, and it is expected that significant Improvements in tool design, tool materials, process control, etc., will continue. It is believed that the full potential of friction stir welding is unknown, but will be dictated by imagination and limited by Investment. Significant development and growth of the process is inevitable.

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