FRICTION STIR WELDING

Scope of the project:

FSW is a relatively a new technique which has been systematically developed for joining aluminium and magnesium alloys. An environmentally cleaner process has been invented at The Welding Institute (TWI),UK. FSW is an emerging solid state joining process in which the material that is being welded does not melt and recast.

Objective:

To weld the similar and dissimilar alloys (Al,Mg etc..) which is difficult in traditional welding. To analyse the mechanical properties and microstructure of the welding metal for its application.

The leading-edge technology of Friction Stir Welding allows us to continually identify new joining applications for extrusions, castings, plate, and sheet for customers ranging from railcars to aerospace. Materials best suited for FSW and offers solutions to improve product performance, quality, and weld development. The influence of process parameters on micro structural characteristics & mechanical properties of AZ80A Mg alloy during friction stir welding (FSW) are investigated in a detailed manner. The tensile fracture surfaces obtained from successfully fabricated joints are subjected to tensile tests and micro structural investigations were done using scanning electron microscope.

From the experimental results, the joints produced under a 5 kN axial force value at 1000 rpm and at a feed rate of 1.5 mm/min were found to exhibit superior

Mechanical properties and metallurgical defect free weldments when compared with other joints. The chemical compositions of these defect free joints were analyzed using energy dispersive spectrometry. Moreover, ideal level of heat generation, uniform flow of the plasticized material and formation of fine grain structure with uniform distribution in the FSW zone were found to be the main reasons for these superior mechanical properties and flawless joints.

Experimental investigation was conducted to find out microstructural characteristic changes arising in the weldments AZ80A Mg alloys obtained using the friction stir welding. Tools with three different pin profile geometries were employed during this investigation at constant tool rotational speed and feed rate. Tensile tests are performed and the tensile fracture surfaces are examined using the Scanning Electron Microscope (SEM) and the obtained SEM images are used for microstructural investigations. From the experimental results, it was observed that the geometry of the tool pin plays a significant role in producing essential stirring action there by regulating the flow of the plasticized material and leading to the formation of small sized grains having equally distributed fine strengthening precipitates. These structured grains have a direct reflecting impact in increasing the hardness and mechanical properties of the fabricated joints at the nugget zone of the friction stir welded AZ80A Mg alloy joints.

Introduction

Invented, developed & patented in the year 1991 by The Welding Institute (TWI), Friction Stir Welding (FSW), is an incomparable, attractive, hot shear joining / welding technique comprising a rotating tool which is non-consumable in nature. Using FSW, weldments free from defects (including hot cracking, alloy segregation, porosity etc.,) with appreciable & better mechanical properties and excellent surface finish are obtained in a variety of aluminium, copper, magnesium, titanium alloys, which were previously having some limitations & constraints during their conventional welding processes. Further, the need for the post welding cleaning of the alloys is completely eliminated when the alloys are welded using FSW. Moreover, an absence of the melting of the base metal provides more benefits to the friction stir welding process compared with other conventional welding techniques. These various attractive and promising characteristic features of FSW make them to be one of the most preferable fabrication processes for joining Mg alloys.

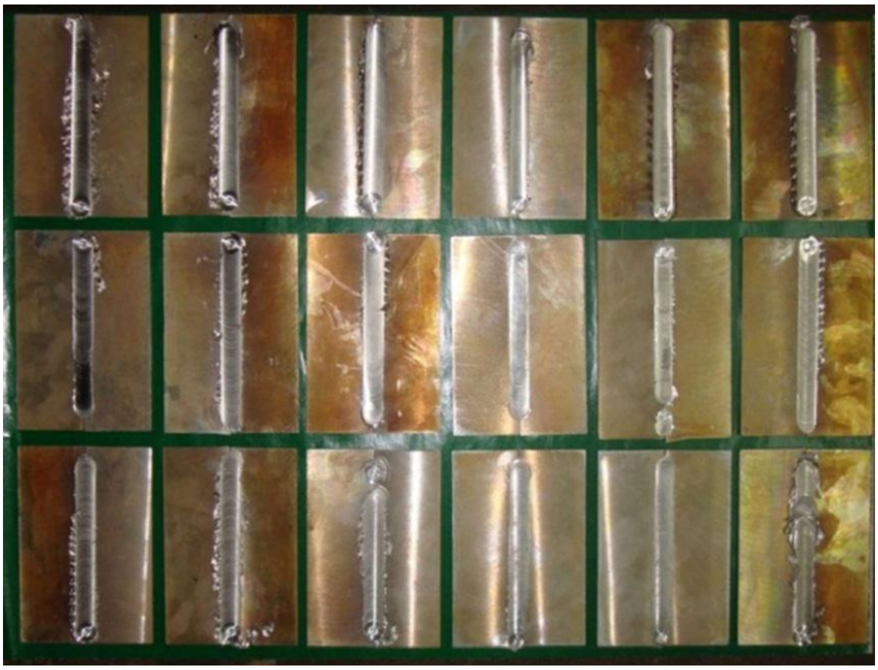
Experimental investigation detail

AZ80A magnesium alloy is taken as the base material in this present investigation. The required thickness of 5 mm of the AZ80A magnesium alloy was obtained by machining the rolled plates to the required dimension. The rolled plates are then machined to required width & length (50×150 mm) using power hacksaw followed by the milling process. The chemical compositions of the base metal i.e., AZ80A magnesium alloy are listed in Table 1. This alloy had strength (tensile) of 289 MPa, strength (yield) of 191 MPa and percentage of elongation being 8.9%. A square butt configuration (150×100 mm) was prepared to enable the joining of the AZ80A pieces together by means of friction stir welding technique.

EDS (energy dispersive spectrometric), SEM (scanning electron microscopic) images and optical micrographs of the base metal i.e., AZ80A Mg alloy are illustrated. EDS analysis shows the composition of the base metal and estimates the weight percentage of elements in a quantitative manner. Existence of unevenly distributed Al12Mg17 coarse intermetallic compound structures can be observed along the entire coarse grains from the SEM micrographs of the base metal. Presence of coarse grain structure together with a reasonable amount of sub grains can be seen in the optical microscopic image of the base metal

Experimental Methods

A part of the joints fabricated successfully during the friction stir welding of the AZ80A magnesium alloys using M35 grade HSS tool with three different pin profiles under various axial force values at constant tool rotational speed and feed rate are displayed in Fig. 3. By analyzing the macrostructures of the joint surfaces fabricated in this investigation, it was observed that the geometry of the tool pin profile has played a significant role in determining the quality of the weld through their influence in the stirring action during the weld, flow of the plasticized material, generation of heat. From the macrostructures, it was found that the defect free sound weld joints were obtained during the use of tool with taper cylindrical pin profile at 3 KN axial force condition.



Photographic illustration of the part of the fabricated AZ80A Mg Alloy specimens by FSW

MICROSTRUCTURAL EVOLUTION AND THEIR CHARACTERISTICS

By carefully examining the microstructural images as shown, it can be visualized that there is a reasonable amount of difference in the size of the grains present at the nugget weld regions when compared with that of the size of the grains present in the base metal. It can also be noticed that the coarse unevenly distributed grain structure of the base metal have been transformed into an uniformly distributed fine grain structure at the nugget centre region in the fabricated joints. The ASTM: E112 – 10 methodologies was used to determine the average size of the grains in the centre of the nugget zone of the fabricated joints.

The average diameter of the grains present in the base metal are measured to be 29 μm, but the average diameter of the grains present at the nugget centre zone of the joints fabricated using taper cylindrical pin profile under 3 kN axial force (Joint No. 9) was measured to be only 8 μm. This measured difference in the grain size reveals us that there are 21 μm reductions in the diameter of the grains present at the nugget region. This shows us that the FSW causes refinement of grains during the process and produces joints with finely refined grain structures when compared with that of the base metal. Apart from the various available optical micrographs taken at different regions of the welded joints, the micrographs illustrating the interface of the stir zone (SZ) with the thermo mechanically affected zone (TMAZ) on the advancing side (AS) and retreating side (RS).

It can be noticed that during the FSW process, the extrusion of the metal takes place in the AS and this extruded material has been dynamically recrystallized and redeposited on the RS. This extrusion, recrystallization and re-deposition process is a characteristic feature of the FSW process. Additionally, this has resulted in the formation of comparatively finer grains on the retreading side of the TMAZ when compared with that of the grains in the TMAZ on the advancing side. From the microstructural images shown, it can be seen that the grains in the stir zone are uniformly distributed and finer when compared with that of the grains in the TMAZ. Further, the grain size (average diameter) and its distribution in the TMAZ seem to be greatly influenced by the stirring action of the tool pin profile. The joints fabricated with taper cylindrical pin profiled tool employing 3 kN axial force (Joint No. 9) have found to possess grains with relatively fine structure both at the TMAZ and RSTMAZ (Retreating side of the thermo mechanically affected zone) of the fabricated joints compared to those in other joint specimens.

CHARACTERIZATION OF VARIOUS FSW ZONES

The detail the micro structural image of the various regions of the defect free sound quality welded joint (Joint No.9) obtained using trinocular metallurgical microscope. From these images, it can be noted that the grain structure exhibiting the presence of large coarse size grains with non-uniform distribution have been completed transformed into evenly distributed, comparatively fine sized grains at the nugget zone during the FSW process. These in turn have resulted in the fabrication of sound quality joints which are completely free from defects. The parent metal microstructure of AZ80A Mg alloy with cast microstructure of dendrite network. It can also be seen that the base metal contains cored grains of magnesium solid solution with massive precipitates of Al12Mg17 precipitates at the grain boundaries. The interface zone at the advancing side. The left side of the picture interface zone at the advancing side. The left side of the picture represents the parent metal microstructure and the right side shows the nugget zone. It can be observed that in this region, the effect of temperature and the stress has lead to good flow of the fusion zone with the fragmented particles which have recrystallized. Depicts in detail the nugget zone microstructure along with the grains formed due to super plasticity of metals with dynamic recrystallization. From the optical microstructural images, it can be recorded that the nugget region of the defect free joints are found to possess very fine, homogeneous, equiaxed, unidirectional grains. This is due to the occurrence of the dynamic recrystallization produced by the combined effect of the tool pin profile geometry and axial force values. From these images, it can be noted that the grain structure exhibiting the presence of large coarse size grains with non uniform distribution have been completed transformed into evenly distributed, comparatively fine sized grains at the nugget zone during the FSW process. These in turn have resulted in the fabrication of sound quality joints which are completely free from defects.

Fracture Surface Analysis

The joints produced using taper cylindrical pin profiled tool geometry under a 3 kN axial force value at a tool rotational speed of 750 rpm and feed rate of 50mm/min (Joint No. 9) is observed through SEM and micrographs were obtained for the three different zones of these friction stir welded joints and are illustrated. The first interface junction of parent metal and the nugget zone i.e., the heat affected zone (HAZ). In this zone, stirring process had taken place nicely and marginal flow of thermo mechanical transformation of the grains can be seen. The precipitates of Al12Mg17 seem to be completely dissolved and partly fragmented due to the thermal and stress effects resulting from sufficient amount of heat generation caused by the 3 kN axial force. The microstructure at the nugget zone is portrayed. It can be noted that due to the high stirring action of the taper cylindrical pin profiled tool, the grains have directed along the rotational axis. The white precipitates of Al12Mg17 have found to be fragmented and elongated. The matrix magnesium grains have also found to be plastically deformed along the axis of the tool. Fig. 6c shows the thermo mechanical transformation zone with clear flow of grains along with the precipitates of Al12Mg17 and the grain fragmentation has taken place in a proper manner which has resulted in sufficient plasticity of the material. Moreover, the Energy Dispersive Spectrometry (EDS) results were obtained for the nugget zone and the results are summarized. From the SEM fractographs in presence of dents and clefts invariably in all the fractured specimens can be seen which reveals us that all the fabricated joints have failed in ductile mode, irrespective of their heat input (axial force value) and tool pin profile geometry used during their FSW process. Yet, small variations can be found in the size and shape of the dents, which has occurred due to the variation prevailing in the nugget zone. The fractograph of the joint fabricated using taper cylindrical pin profiled tool geometry under a 3 kN axial force condition (Joint No. 9) consist of depressions, indicating the occurrence of cup and cone type fracture. This category of fracture pattern takes place only when the material undergoes uniform distribution. The possibility of achieving uniform distribution in the friction stir welded joint is viable only when the nugget zone is free from macroscopic level of defects.

EFFECT OF TOOL GEOMETRY

The fundamental role of the FSW tool pin is to uproar the metal in the plasticized state and to permit movement of this plasticized metal back of it, thereby enabling the fabrication of good quality welds. Photographic illustration of the part of the AZ80A Magnesium Alloy specimens before and after the friction stir welding process under various process parameters using different pin profiled tools significant role in facilitating the flow of the plasticized metal, thus helping in regulating the uniformity of the welded joint. The tool pin geometry has a direct impact on the heat generation, plasticity of the metal and the uniformity of the weld [15]. The comparison of the mechanical properties produced using the different combinations of the tool pin geometries and axial force values at constant tool rotational speed and feed rate are graphically illustrated.

Conclusion

From this experimental investigation, the derived conclusions are mentioned below:

• The geometry of the tool pin plays a significant role in producing essential stirring action there by regulating the flow of the plasticized material and leading to formation of small sized grains having equally distributed fine strengthening precipitates. These structured grains have a direct reflecting impact in increasing the hardness and mechanical properties of the fabricated joints at the nugget zone of the friction stir welded AZ80A Mg alloy joints.

• Tools with three different pin geometries (straight square, straight cylindrical and tapered cylindrical) were used in this investigation. Out of these three different tool pin geometries, tapered cylindrical pin profiled tool exhibited joints with appreciable properties and hardness values when compared with other two tool pin geometries.

The microstructure of these defect free joints is found to possess very fine, homogeneous, equiaxed, unidirectional grains. This is due to the occurrence of the dynamic recrystallization produced by the combined effect of the tapered cylindrical tool pin profile and 3 kN axial force values.