A review on friction stir welding of aluminium metal matrix composites

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Abstract. In the emerging world of technology, metal matrix composites have been playing the vital role in various applications to reduce the weight, increase the physical properties like hardness, tensile strength etc. Among these Aluminium metal matrix composites are the ones where the research is concentrated since Iron and steel can be replaced by Aluminium because of their properties. Thus, the usage of such composites in daily life is difficult because of the tough joining combining process like welding, casting etc. In this paper we are going to review the effects of such Aluminium metal matrix composites when joined using Friction Stir Welding and the related effects on the materials.

1.0 Introduction

In this review paper we have stated the effects of Friction Stir Welding on different composites of Aluminium as base material and formulating the results from the resulting material. The different tests have been made on the composite materials by viewing the different physical properties of it. The different advantages of using FSW is also seen in the following review paper.

2.0 Friction stir welding in aluminium-SiC metal matrix composite

Paola Bassani et al [2007] studied the effect of laser welding of the MMC using a CO2 and diode laser source. He has found out the most efficient method of welding from these two processes. The CO2 method of welding is done under deep penetration conditions and the diode laser uses a conduction welding method. From the results he has found that the CO2 welding process leads to the formation of Al4C3 which is found to decrease the toughness of the bead, while the laser welding process seems to give less formation of Al4C3 which is good and gives a good quality bead compared to C02 method of welding. Also the laser diode has emerged to be the best method in terms of high efficiency and high radiation wavelength absorption rate by the MMC’s when compared with CO2 welding process. Rotundo et al [2010] has done his research on the effect of using Linear Friction Welding to make defect free joints in 2124Al with reinforcing material as SiCp of 25 vol%. The MMC joints were tested then at microstructural level and mechanically characterized on the basis of hardness, tensile, fatigue without and weld heat treatment process after LFW. The results showed that the joints produced were defect free with a uniform distribution of particles in the centre zone and the plasticity nature in the aluminium metal matrix obtained is reasonably good as expected. The decrease in hardness at the welded zone was 10% of hardness of the base material. The efficiency of the metal matrix joint produced by FSW was found to be more than 80%. Similarly, the S-N probability curves...
were also obtained with reasonable results. The only defect occurring was the fracture occurring at the Thermo-Mechanically Affected Zone (TMAZ). Won-Bae Lee et al [2006] has studied the effect of FSW on AZ91 Mg alloy with the reinforcing particles as SiC and has found the micro-structural property and the wear produced. The AZ91/SiC/10p microstructures initially were made up of irregularly distributed β-phases (Al12Mg17) and a collective mass group of SiC particles. The joint consisted of evenly distributed particles of SiC in a recrystallized manner and resulted in β-phase dissolution. Finally, the results showed that the composites hardness and wear resistance increased in the welded zone due to microstructural modification when compared to the base metal. Wei Wang et al [2009] investigated the effect of making Al metal matrix composites with bulk dispersal of SiCp reinforced in it. The SiCp were well uniformly distributed over a range of 5mm × 2mm on the cross section of the joint. About 1.5% of SiCp was found in the reinforced region which was not restricted to 100µm magnitude on the upper surface of the matrix. The hardness at the micro level reached up to 10% higher steady state than the base metal at a depth of 1.0mm down the upper surface. Zadi et al [2013] used the method of Friction Stir Process (FSP) to redefine the micro level structure of sintered Al-SiC composites with the concentration of the particles ranging over 4 to 16 vol%. Initially two SiC particles of sizes (490N and 800 grades) were checked for. The results showed that for the composites containing 4 and 8 vol% of 490N grade SiC gained an increase in hardness from 130 HV and 145 HV to 171 HV and 177 HV respectively. This was due to the uniform distribution of the SiC particles during FSP. While, the composites which contained 16 vol% of SiC gave bad results due to the formation of residual pores and lack of mass grouping. Therefore, the composites containing 4 and 8 vol% of SiC showed better inter particle mean spacing than the use of 16 vol% of SiC particles. Devaraju Aruvi et al [2013] examined the impact of tool rotational speed on mechanical and wear properties of aluminium alloy based composites using Friction Stir Processing and the resulting surface was studied using an optical microscope for finding the extent of dispersion of reinforced particles. The results showed that the micro level structures of hybrid composites with the acting reinforced particles namely SiC, Gr and Al2O3 were found to be evenly distributed in the small zone. The micro level hardness was found to be decreased by increasing the rotational speed and showed greater value in the Al-SiC composite and Al-Al2O3 composite surface due to the action of SiC and Al2O3 particles respectively. Also, the Aluminium and SiC/Gr (reinforcing materials) hybrid composites showed high wear resistance as the SiC particles worked as a load bearing element and Gr particles worked as a lubricant.

3.0 Friction stir welding in aluminium-Al2O3 metal matrix composite

Ceschini et al [2007] investigated the effect of Friction stir welding of Aluminium alloy (AA6061) reinforced with 20% volume fraction of Al2O3. The tests are carried out without any heat treatment after welding process. The results show that there is a reduction in amount of reinforcement particles up to 60% near the weld zone. It also contributes to the refinement of grains in the Friction stir welded sample. The microhardness, proof strength and ultimate tensile strength is also decreasing gradually of 60%, 43% and 28% respectively from the base material to that of the welded region due to over raging of Aluminium whereas Failure of elongation increased by 64% and low cycle fatigue life was less than that of the base material. Ceschini et al investigated the effect of friction stir welding of Aluminium alloy (AA7005) reinforced with 10% of alumina particles by employing a tool rotating speed of 600 rpm and a welding speed of 250 mm/min. The optical and scanning electron microscopy observations performed on the different zones of FSW joints cross-section revealed the different structures of the nugget, the thermo-mechanical affected zone and the heat affected zones. There occurs a strong grain refinement produced by the dynamic recrystallization. Fatigue tests were carried out under pulsating, tension loading using a resonant electro-mechanical testing machine. All the mechanical tests were performed up to failure which occurred at the interface with the welded area. The strong deformation of the material during the process leads to a strong grain size reduction. A fatigue life of 2 · 107 cycles was recorded for a stress amplitude of 120 MPa. Pirondi and Collini [2009] carried out analysis on fatigue crack propagation resistance of particulate metal-matrix composites butt joints obtained by
friction stir welding. Two different alloy namely Al 6061 and Al7005 reinforced with 20% and 10% Al2O3 respectively were under test. The results showed that the fracture toughness of the FSW joint is about 25% lower than the parent material in the case of W6A20A, while it is 10–20% higher in the case of W7A10A and crack propagation rate is lower than in the parent material in the case of W6A20A, while it is higher in the case of W7A10A. The comparison between parent material and joint showed that the welding process affects fracture toughness and fatigue crack growth rate differently depending on the material. Marzoli et al [2006] established the friction stir welding (FSW) process parameters envelope for an AA 6061 alloy reinforced with 20% of Al2O3 particles and he also explained the difficulties in joining MMCs. Microstructure has been observed with optical microscope, and images have been analysed with an image analysis software. Microhardness and tensile tests have been also carried out. The tools stirring effect has a substantial influence on the reinforcement particles distribution and shape. It has been found that the particles which were larger in size with edges being sharp would break way, making them rounded. The tensile testing of welded specimens revealed joint efficiencies of over 80% for the YS and of slightly more than 70% for the UTS. Failure in tensile testing always took place outside the stir zone.

4.0 FRICTION STIR WELDING IN ALUMINIUM ALLOYS

Fratini et al [2010] has experimented the Friction Stir Welding of titanium alloys which in his case is the more challenging as the material has intricate thermos-chemical characteristics. The main aim is to increase the mechanical performance of the welded regions. The FSW of titanium blanks was performed and the mechanical and metallurgical tests were carried out showing the properties of FSW of titanium alloys. Results show that the microhardness level increase with decreasing average grain size. Tracie Prater [2014] has presented his research paper on the extent of usability of MMC’s in the aerospace industries. He has extended his research on the effect of tool wear in FSW. He has explained that the wear process in FSW is due to a shear instead of a drag. His results show that he best way to tackle wear is to use a tool material which is harder than the reinforcement particles and use reinforcement particles which comes at the top order in the FEPA scale. He also states that diamond coatings are the best alternative as a wear resistant tool material. Minak et al [2010] has mainly concentrated on the fatigue factor of FSW joints on an aluminium based composite (AA6061/22 vol.% Al2O3p). The composite specimens obtained had an adequate increase in micro hardness property and showed an superior joint efficiency when compared to the tensile strength of the material. Although the analysis of fatigue resistance was very poor for the FSW specimens obtained with different process parameters. The failure mostly occurred in the stirred zone on the application of high loads and fine reinforcement particles in the fractured zone were visible. Heurtier et al [2006] has investigated the thermomechanical model in three dimension for FSW process. He has presented his views on the temperature estimations and microhardness levels in different weld zones. Results show that the increase in velocity of the tool smoothens the hardness profile close to the bulk zone and it is mainly due to the decrease in the temperature near the weld zone. Meshram et al [2007] has pointed out the necessity of joining dissimilar metals in the industries and has given a solution for it by using FSW process. The commonly used metal combinations are Cu-Ti, Fe-Ti, Fe-Cu, Fe-Ni. His research points out that he has taken the pure form of each dissimilar metal and has joined them using FSW process. His results prove that an increased time of interaction led to the reduction in strength in insoluble system and gain in strength in soluble system. Darras et al [2007] has experimented the FSW of commercial AZ31 magnesium alloy as most of the research papers have been concentrated on aluminium alloy. The effect of FSW on magnesium alloys is dynamically reported and it is shown that microstructure properties of magnesium alloys have tend to be increased and homogeneous grain structure and recrystallized structure is also obtained in the FSW weld zone. Adem Kurt et al [2011] has studied the effect of reinforcing SiC particles into pure form of aluminium. The composite samples were then tested at different tool rotating speeds and traverse rates. The microstructural results showed that by increasing the effect of tool rotating speed and traverse rate gave a even distribution of SiC particles in the base material and also the hardness property was three
times more than the base parent metal. Results also showed an increase in bending strength of the metal matrix composite which was the ultimate aim of this study. Dora Siva Prasad et al [2014] utilised the method of double stir casting in his experimentation. The aluminium base material is reinforced with different proportions of rice husk ash namely 2,4,6 and 8 wt% and SiC particles in a similar proportion. The mechanical properties such as hardness, density, porosity of the resulting composite has been viewed in detail. For this purpose, SEM observations have been made and finally it was seen that hardness, porosity, ultimate tensile strength and yield strength increased significantly with decrease in density of the composite material. The precipitation kinetics of the resulting material was also found to be greatly increased. Kunal Yeole et al [2014] has used the technique of including a layer of zinc oxide nanoparticles on the upper surface of fly ash by a unique chemical method. The zinc oxide is known to be corrosive in nature. With the differing concentrations of fly ash being 5, 10, 15(w/w) % of zinc oxide, the results were rather pleasing with the increase in crystallinity and reduction in size of the particle, specific gravity and oil absorption rates which is due to evenly distribution of zinc oxide particles on fly ash. The main use of this nanocomposite is it features as an anticorroding coater by serving as an additive. Dora Siva Prasad and Chintada Shoba [2014] has experimented the wear resistant property of hybrid aluminium composite with the main reinforcement particles as rice husk ash and SiC particles with a proportion of 8%. The test carried out was pin-on desk wear test and SEM observations are made out to study the given characteristics. Results made out were quite positive with the increase in wear resistance of the hybrid composite which was the sole purpose of the experiment. Storjohann et al() made out an investigation by comparing the method of fusion welding of Al-MMC’s and FSW matrix composite. Both showed their own positive results as fusion welding tends to increase the hardness of the Al base material due to formation of aluminium carbide(A14C3) needle like structures in the welded region while the later method proved to produce an evenly distributed microstructure with an even hardness nature which was not seen in fusion welding of Al-MMC’s. Yahya Bozkurt et al [2011] has presented his research topic on the friction stir welding of AA2124 consisting of 25% of SiC particles in hat treated T4 aluminium MMC plates and more importantly at low welding parameters. The composite was also tested for heat dissipation from a specific distance of 15mm from the weld portion. The results showed an increase in Ultimate tensile strength which resulted in a improved joint efficiency of approximately 73%. Gan et al [2010] in his research paper has provided a basic view of the use of friction stir welding process in the various manufacturing industries and aerospace industries. He has pointed out that FSP is very useful when it comes to increasing the microstructural characteristics of the base material by reinforcing it with particles. His results show that the FSP method increase the hardness and other challenges met are in increasing the fatigue factor and joint strength. Some parameter studies are done by varying process parameters [23,24,25].

5.0 Conclusion

The various physical properties such as hardness, toughness have been found to be increased and The density and strength to wear ratio has found to be decreased and there is an uniform grain distribution of the particles in the welded zone. Therefore, Friction Stir Welding process is more efficient than the other methods of preparing composites.

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