Effect of Fly Ash and SiC Particles on Hardness and Microstructure of Friction Stir Welded MMCs

Sachinkumar, S. Narendranath and D. Chakradhar

Abstract--- *Metal matrix composites (MMCs) constitute an important class of design and weight efficient structural materials that are encouraging every sphere of engineering applications. Since, there has been an increasing interest in composites containing low density and low cost reinforcements. In the present work, Friction Stir Welding (FSW) has been used to join the AA6061 reinforced with SiC and Fly-Ash hybrid metal matrix composites (MMCs). Accordingly, rectangular composite plates were fabricated through stir casting route, then these plates were welded by using FSW. Micro-structural characterization of the stir zone was carried out through Optical Microscopy (OM). The uniform grain distribution was observed across the stir zone of AA6061/SiC/Fly-Ash composites after FSW. In addition, the evaluation of hardness was carried out and observed that a considerable increase in the hardness in the weld nugget zone when compared to the base metal for all percentage composition of fly Ash particles across the stir zone resulting successful method for FSW of AA6061/SiC/Fly-Ash composites has been developed.*

Keywords--- *Friction Stir Welding, Hardness, Microstructure, MMCs, Fly-ash, Silicon Carbide*

I. INTRODUCTION

METAL Matrix Composites (MMCs) are fetching very attractive automotive, aerospace, marine and many other applications due to their admirable physical and mechanical properties [1],[2],[3]. Among MMCs the particle reinforced aluminum matrix composites (AMCs) are really attractive because of their low cost, isotropic properties [4], [5].

In order to broaden the wide utilization of AMCs, effective and efficient joining techniques such as solid state welding and fusion welding become of practical importance. However it is difficult to achieve defect free welds by employing conventional fusion welding techniques due to the presence of ceramic particles, problems such as incomplete mixing of parent and filler material and deleterious chemical reaction between reinforcement and parent metal, the presence of porosity, and formation of excess and deleterious phases are difficult to avoid in the joints produced by conventional fusion welding methods [6],[7]. In such cases, solid state welding

methods are highly desirable to achieve potentially good AMC joints.

As a solid state welding technique, friction stir welding (FSW) is a rapidly developing and has proved to be successful and effective welding method for joining Aluminum alloys [8], [9]. It is considered a promising welding method for joining of AMCs because the drawbacks of fusion welding can be avoided in FSW. In the past few years, joining of AMCs using FSW was attempted and the microstructures and mechanical properties of the FSW joints were studied, including $Al_2O_3p/AA7005$ [10], [11], Al_2O_3p AA6061 [11], [12], [13], [14], [15], SiCp/AA2009 [16], [17], [18], [19], $B_4Cp/AA6061$ [20], TiB_2p/Al [21], $Mg_2Si/Al-9.7Mg-5.5Si$ [22], and $TiCp/Al$ [23]. FSW has been shown to result in a more homogeneous distribution of the particles and their breakup and bluntness due to the effect of severe plastic deformation and material mixing, furthermore, the grain sizes of the matrices were greatly refined due to dynamic recrystallization.

Although several studies on FSW of AMCs were reported, a small number of researches are also studied on FSW of hybrid AMCs, but no literature is available to study the effect of low cost reinforcement like fly ash on the welded strength using FSW.

In this study 6mm thick Al6061/SiC/Fly Ash composite plates produced by stir casting route are welded by Friction Stir Welding and then microstructure and hardness in the nugget zone were examined carefully.

II. EXPERIMENTAL DETAILS

The chemical compositions of Al6061 and Fly Ash are provided in Table 1 and Table 2 respectively. AA6061-10%SiC reinforced with 3% (wt.%) Fly Ash composite was produced by stir casting process with bottom pouring arrangement. Plates of size 100 mm x 50 mm x 6 mm were prepared from cast composite using machining process. The butted plates were placed on a rigid backing plate and firmly held by means of a specially designed fixture. A non-consumable rotating tool made of hot work tool steel H13 with cylindrical threaded profile pin.

Sachinkumar, Research Scholar, Department of Mechanical Engineering, NITK, Surathkal, India. E-mail:sachindongapur1@gmail.com

S. Narendranath, Professor Department of Mechanical Engineering, NITK, Surathkal, India. E-mail:snmath88@yahoo.co.in

D. Chakradhar, Assistant Professor, Department of Mechanical Engineering, NITK, Surathkal, India. E-mail:chakradhar.dupadu@gmail.com

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Table 1: Chemical Composition of Al6061

Element	Weight%
Mg	1.58
Si	0.67
Ti	0.2
Cr	0.2
Mn	0.22
Fe	0.6
Cu	0.27
Zn	0.17
Al	Balance

Table 2: Chemical Composition of Fly ash particle

Element	Weight %
Al ₂ O ₃	30.06
SiO ₂	63.51
MgO	1.54
TiO ₂	0.99
Fe ₂ O ₃	3.9

The welding process was carried out on a 10 tonnes capacity ETA horizontal stir welding machine. The tool was inclined at an angle of 2° backward with respect to normal of the workpiece. The rotating tool was plunged into the abutting edges of the plate until the shoulder touches the surface with sufficient plunge force. After a dwell period of 15 seconds, the machine table was moved at a predetermined welding speed. When the plunged tool reaches the other end, the tool was retracted. This process was repeated for different combinations of welding process parameters. Figure 1 represents the friction stir welding set up, Figure 2 represents the welded composite plates by FSW. The welded specimens were cross-sectioned perpendicular to the welding direction from joints. These specimens were polished with a diamond paste and finally etched with Keller's reagent. Then using Optical Microscope, microstructures of the welded joints at the nugget zone have been studied. Vickers hardness tester was used to measure the hardness of the welded specimen at nugget zones of the weld. The hardness tests were performed at three different places on the nugget zone and their mean is taken as final hardness number.

Fig.1: FSW Setup

Fig. 2: Welded Composite Plates by FSW

III. RESULTS AND DISCUSSIONS

Fig.3(a)

Fig.3(b)

Fig. 3: (a) Welded AMCs Specimen, (b) Microstructure Image of Parent AMCs, (c) Microstructure Image of Welded Region

Optical Microscopy image of hybrid AMC parent material microstructure is shown in Fig. 3(a) and the microstructure of hybrid AMC after welding with various zones is shown in Fig. 3(b) and Fig. 3(c) shows microstructure of nugget zone. The parent AMC has a dendritic structure, as it is produced by using stir casting process. The dendritic structure of the parent metal shows dispersion of SiC particles in the AMC. The microstructure of FSW is classified into mainly three regions namely, heat affected zone (HAZ), thermomechanically affected zone (TMAZ), and weld nugget zone as shown in Fig. 3 (c) [24],[25],[26]. It clearly reveals the different grain sizes in the interfacial boundary between the TMAZ and weld nugget is shown in the fig 4.

Fig. 4: FSW Weld Showing Four Distinct Zones: (A) Base Metal (B) Heat Affected (C) Thermomechanically Affected and (D) Stirred (nugget) Zone

The weld nugget zone was a slightly larger than the size of the rotating pin, irrespective of width and height of the pin. On the other hand, the size of the zone will vary with frictional pressure, forging force and friction time. As the friction time is reduced, the large amount of thermal energy is propagated in the direction of work piece which will increase in the size of the nugget zone [24]. The weld nugget surrounded by TMAZ, having well deformed and elongated coarser grain due to the stirring action of the tool. However, in this region plastic deformation and dynamic recrystallisation is a bit lesser than weld nugget region. In this study, threaded cylindrical pin FSW tool is being used which provides energetic stirring action in the flowing material due to threads which results in formation of finer grains [27].

To characterize the hardness of the weld region of the FSW, Vickers hardness testing machine was used. The hardness of the nugget zone is found to be higher than that of the base composite irrespective of the tool rotation and weld traverse speed. The breakage of SiC particles and refinement of deformation strain [28]. Thus hardness values were found to be lower than nugget zone. The difference in hardness between the HAZ and SZ is attributed to the grain refinement in the stir zone and annealing process in the HAZ [26].

Fig. 5: Vicker's Hardness at Nugget Zone v/s Spindle Speed

Fig. 6: Microstructure of Welded Zone at Various Spindle Speed of (a)600rpm (b)700rpm (c)800rpm (d)900rpm (e)1000rpm (f)1100rpm (g)1200rpm (h)1300rpm

As the tool spindle speed is increases from 600rpm to 1300rpm, the hardness values are also increased at a traverse speed of 50mm/min as shown in the fig 5. This is because, high rotational speed and low welding speed led to increased heat generation and reduced cooling rate, which results in uniform distribution of reinforcement particles.

IV. CONCLUSION

The study demonstrates that, friction stir welding can be successfully adopted for joining Al6061/SiC/FA hybrid AMCs. The microstructure at the nugget zone was characterized by fine and uniform distribution of SiC and Fly ash particles. The clusters present in the parent composite were split by stirring action of the tool. The weld zone can exhibit higher hardness than parent material due to fragmentation, homogeneous distribution of SiC particles and grain refinement. In addition, the evaluation of hardness was carried out and observed that a considerable increase in the hardness in the weld nugget zone when compared to the base metal for all percentage composition of fly ash particles across the stir zone

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Sachinkumar graduated in mechanical engineering and received M.E in Manufacturing science and engineering from Bangalore University, Bangalore in 2012. Presently he is persuing PhD in Friction Stir Welding of MMCs at National Institute of Technology Karnataka, India. He presented Friction Stir Welding based papers in national and international conferences. His areas of interest include Friction Stir Welding, Machining and Casting.

Memory Alloy, Welding technology.

Dr.S.Narendranath graduated in Mechanical engineering from Mysore University of Karnataka. He received M.Tech from kuvempu university and PhD in Materials form IIT Kharagpur. Presently he is working as Professor in the department of mechanical engineering at National Institute of Technology Karnataka. His areas of Interest includes Advanced Manufacturing and Technology, Machining of advanced materials, Severe Plastic Deformation, Shape

Design of Experiments, Design for Manufacture.

Dr.D.Chakradhar graduated in Mechanical engineering from SK University, Anantapur. He received M.Tech from National Institute of Technology Warangal and PhD in Non-Traditional Manufacturing from National Institute of Technology Warangal. Presently he is working as Assistant Professor in the department of mechanical engineering at National Institute of Technology Karnataka. His areas of interest include Non Traditional Manufacturing Processes