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RESEARCH ARTICLE

EFFECT OF FRICTION STIR PROCESS ON IN-SITU ALUMINUM ALLOY Al6061-T6/Al3Ni

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ABSTRACT

Aluminium matrix composites (AMCs) have gained considerable amount of research emphasis and attention in the present era. Research is being carried out across the globe to produce new combination of MMCs. MMCs are prepared by adding a variety of metal particles with monolithic alloys using several techniques. An attempt has been made to produce aluminum metal matrix composites reinforced with nickel (Al3Ni) particles by the in situ reaction and applying friction stir processing. When the specimen was stirred 2 passes, the formed Al3Ni was tiny to be detected. Al3Ni subsequently became apparent when stirring 4 passes and the fine Al3Ni particles were dispersed homogeneously in the composites The microstructures of the material were investigated. The results showed that the microstructures Friction stir zone were uniform and with small equiaxed grains in in-situ AMCs.

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INTRODUCTION

In situ aluminum matrix composites (AMCs) were typically produced through one or more reactions between aluminum and oxide ceramics such as TiO_2 (Zhu *et al*., 2012; Zhu *et al*., 2013), SiO_2 (Zhu *et al*., 2014) and ZrO_2 (Zhu *et al*., 2010; Feng and Froyen, 1999). These composites are applications due to their high specific strength and toughness, good thermal stability and wear resistance. The casting methods used for fabricating in situ AMCs (Chen *et al*., 2008). Aluminum rich intermetallic particles such as Al_3Ti, Al_3Zr, Al_3Fe, Al_3Ni, Al_2Cu and Al_3C_4 are potential reinforcements for Discontinuously reinforced aluminum matrix composites (DRAMCs) because they have a low density and coefficient of thermal expansion, high modulus and melting temperature and good recycling behavior. Moreover, they are in thermodynamic equilibrium with the aluminum matrix which enables to create a real chemical bond between the aluminum matrix and the intermetallic particle (Varin, 2002; Arik, 2004; Hsu *et al*., 2005). Liquid method of processing is effective owing to its simplicity, easy of adaption, and applicability to large quantity fabrication. Liquid method of processing involves either adding ceramic particles externally to the molten metal or synthesizing in the melt itself. In-situ fabrication involves synthesizing the reinforcements by chemical reactions between elements or between elements and compounds. Fig.1 shows the in-situ fabrication of MMCs schematically. Friction stir processing (FSP) has emerged as a novel solid state technique to modify the microstructure of metallic materials (Ma, 2008). The FSP was derived based on the principles of friction stir welding (FSW) by Mishra *et al*. (1999). FSP uses a rotating tool which is inserted into the surface of the material to be modified and traversed to the required length. The frictional heat and the intense plastic deformation refine the microstructure. The length of the pin determines the depth to which the microstructure is modified. Recently, some investigators used FSP. The morphology and distribution of the Al3Ni particles changed and the tensile strength of the composite improved. Tewari *et al*. (2006) investigated the effect of FSP on microstructure and tensile properties of AA6061/28 vol. % SiC AMC. He reported reorientation of SiC particles and an enhancement of tensile strength. Bauri *et al*. (2011) carried out FSP of Al/TiC in situ cast composites. TiC particles were segregated near the grain boundaries in the composite. FSP removed segregation of TiC particles and distribution of TiC particles became uniform in the aluminum matrix. The mechanical properties improved subsequent to FSP. Izadi *et al*. (2013) applied FSP to Al/SiC powder metallurgy composite. SiC particles clustered all over the composite. FSP dispersed the clusters and improved the mechanical properties. One notable feature in the above mentioned work is that FSP is capable of changing the morphology and distribution leading to an improvement of the properties.

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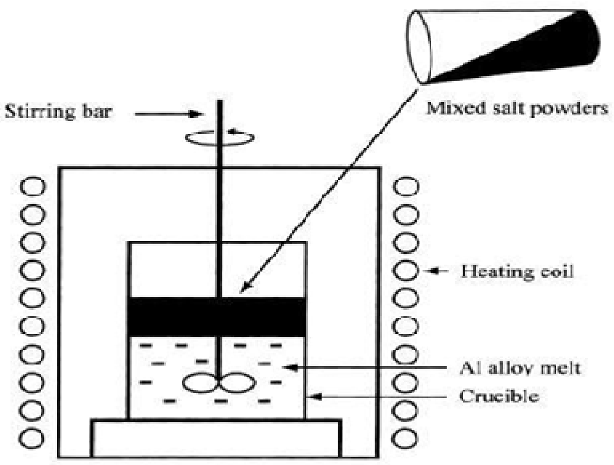


Fig.1. Schematic of In-Situ Fabrication of MMC

Experimental Procedure

Aluminum alloy AA6061-T6 rods were melted in an electrical resistance furnace using a graphite crucible. The average size of Ni particles used in this work was 30µm. The chemical composition of AA6061 is presented in Table I. A coating (WOLFRAKOATC) was applied inside the crucible to prevent contamination at high temperature. Measured quantity of Ni was added into the molten aluminum to form Al3N. The amount of metal particles was computed to yield a target weight percentage of intermetallic particle reinforcement. The temperature of the melt was maintained at 830 ^{0}C to sustain the in situ reaction (Zhao *et al*., 2007). The composite melt was stirred intermittently for 15 min. After removing the slag, the composite melt was poured into a preheated die to solidify. Plates of size 100 mm X 50 mm X 10 mm were prepared from each casting to carry out FSP. The FSP was carried out using an indigenously built FSW machine (M/s RV Machine Tools, Coimbatore, India) at the centre of the plate. The FSP parameters employed were tool rotational speed 1100 rpm, traverse speed 46 mm/min. The press-in depth of the tool shoulder into the plate was set to 0.2 mm, axial force 9 kN and number of passes 2 and 4. A tool made of HCHCr steel, oil hardened to 62 HRC having a cylindrical profile was used Fig.2. The tool had a shoulder diameter of 18 mm, pin of 5 mm diameter and pin length of 5 mm. A specimen was obtained from each friction stir processed plate by cutting in the centre of the plate perpendicular to FSP direction. The specimens were polished as per standard metallographic procedure and etched using Keller's reagent.

RESULTS AND DISCUSSION

Aluminum alloy AA6061-T6 reinforced Al3Ni composites were successfully prepared using in situ casting method into plates Fig 3(a). This indicates that Al3Ni particles were in thermodynamic equilibrium with the matrix. This confirms that there is true chemical bonding between the intermetallic particles and the aluminum matrix. A defect free FSP zone is observed. The FSP zone contains the composite. Typical FSW defects (tunnel, pin hole, piping and worm hole) are absent. The photographs of friction stir processed Al3Ni. The crown of the FSP zone appears to be smooth without any discontinuities or cracks. The crown appearance influences the integrity of the FSP zone. Semicircular features are formed on the crown due to rubbing action of the rotating tool shoulder on the plate. Sufficient frictional heat and material flow at the chosen process parameters produced a defect free FSP zone. Further, the FSP zone is almost symmetric with reference to the tool rotation axis, which indicates that the material flow is uniform during FSP. The uniform distribution of particles can be attributed to adequate generation of frictional heat, stirring and plasticized material flow across the friction stir processed zone in 4 pass Fig. 3(b). Mild agglomerations are also noticed at few locations. The variation in the distribution of particles across the FSP zone was found to be negligible. The digital images of the macrostructure of the FSP zone were captured using a digital optical scanner. It is evident from Fig 3(c). That the FSP zone is almost symmetric about tool axis. The digital images of the macrostructure of the etched specimens were captured using a digital optical scanner Fig.4. The microstructure was observed using an optical microscope. The Microstructure consists of parent composite, transition zone and friction stir processing zone. The various zones are roughly identified by color changes due to different thermo mechanical histories of the friction stir processed plates. The microstructure of cast matrix AA6061-T6, after FSP 2 and 4 pass are presented in Fig. 5. The distribution of Al3Ni particles over the entire matrix alloy. The distribution of Al3Ni particles is observed fairly homogeneous. There is little segregation of particles near the grain boundaries.

Fig.2. Tool used for FSP

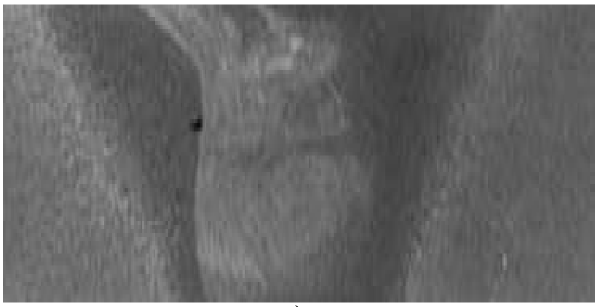
But clusters of Al_3Ni particles are observed at several places in the matrix. Some regions appear to be particle free i.e. no particles are present. But high magnification micrograph shows the presence of nano level Al_3Ni particles in those regions which appears as small white dots in Fig. 5 (a). The shape of the in situ formed Al_3Ni particle was noted to be spherical. The distribution of particles in the aluminum matrix depends upon the stirring of the melt, suspension of particles before and after pouring and solidification induced factors (Hashim *et al*., 1999). The density difference between the particle and the aluminum matrix determines the sinking rate of particles. The density difference between Al_3Ni particles and the aluminum matrix is less than 2.5 g/cm_3 hence, the sinking rate is lower. When Al_3Ni is formed during in situ reaction, the molten aluminum begins to wet the particle. The wetting action provides resistance to the free movement of particles which leads to better distribution and suspension. Further, the melt was stirred intermittently, which promoted suspension of particles for a longer duration.

Table 1. The chemical composition of AA6061-T6 alloy

Element	Mg	Si	Fe	Mn	Cu	Cr	Zn	Ni	Ti	Aluminum
wt.%	0.95	0.54	0.22	0.13	0.17	0.09	0.08	0.02	0.01	Balance

a)

b)



c)

Fig 3.(a) Casted aluminums plate, (b) FSPed plate after 4 pass and (c) Macrostructure of friction stir processed AA6061-T6/Al3Ni

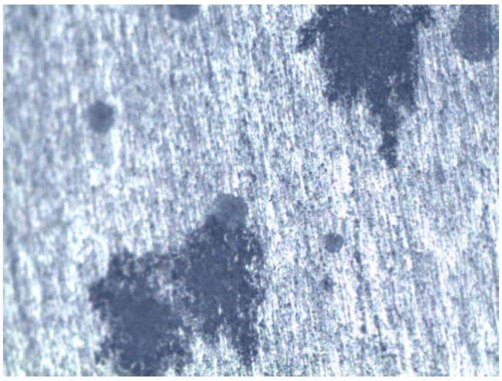
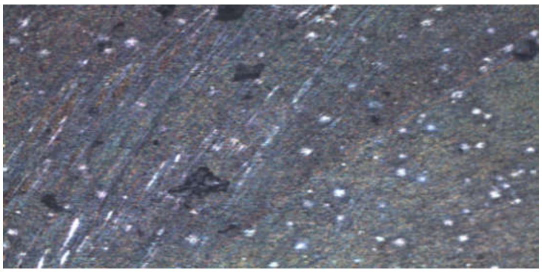


Fig.4. Microstructure of the etched specimens



a)

b)

c)

Fig.5 (a) Microstructure of cast matrix AA6061-T6, (b) after FSP 2 pass and (c) after FSP 4 pass

The solidification related factors are convection current in the melt, movement of the solidification front against particles and buoyant motion of particles. Since the in situ reaction is exothermic in nature, the heat evolved provides good wetting between Al_3Ni particles with aluminum matrix creating good bonding. The effect of 2 pass FSP on the microstructure can be very clearly observed from these Fig .5 (b). Al_3Ni particles are distributed homogeneously in the aluminum matrix. Total rearrangement of particles takes place during FSP. FSP induces severe plastic strain on the plasticized composite which breaks down Al_3Ni clusters. The vigorous stirring action of the rotating tool shatters the clusters into homogeneous distribution. The distribution of particles becomes intra granular after FSP. The segregation of Al_3Ni particles near the grain boundaries disappeared into homogeneous distribution after 4 pass FSP Fig.5 (c)

Conclusion

The Al_3Ni particulate-reinforced composites was fabricated via friction stir processing on Al6061-T6 Al alloy substrate by adding Ni powder by in-situ casting. The following conclusions are drawn. During the process of FSP, the Ni particles and Al matrix in situ synthesized Al3Ni, which was confirmed by microstructure analysis. With 2 passes stirring with Ni powder added, the residual Ni particles were unevenly dispersed in the composites, and few Al_3Ni particles occurred at the peripheries of Ni particles. However, further repeating the stirring to 4 passes, the amount of Al_3Ni particle hardly increased but the particles were better dispersed compared to 2 passes. Because of the formation of ultrafine Al_3Ni particles and uniform dispersion in the composites it will increases the mechanical properties.

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