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Production and characterization of aluminium metal matrix composite reinforced with Al_3Ni by stir and squeeze casting

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Abstract. In the present work AA1100/ Al_3Ni MMC was successfully fabricated using the in-situ method of stirring and squeeze casting. The effects of amount of Ni powder on the formation and mechanical behavior of Al-Al_3Ni MMC were investigated. The fabricated MMC was characterized using XRD and optical microscope. The XRD patterns clearly indicated the presence of Al_3Ni particles without the formation of intermediate phases. The in-situ formed Al_3Ni particles were found to have uniform distribution, good bonding and clear interface. The mechanical and tribological properties such as hardness, Ultimate Tensile Strength (UTS) and dry sliding wear behavior of AA1100/ Al_3Ni MMC were compared for stir and squeeze casted MMCs with different percentage in weight of Al_3Ni (5, 10 wt. %) and it was found that properties improved with increase in Al_3Ni content and all properties of squeeze casted MMCs were superior to stir casted MMCs.

Introduction

Metal Matrix Composite (MMC) technology has become very popular in the past few years. Aluminium intermetallic compounds like Al_3Ni used as reinforcements in aluminium matrix composites and they have high resistance to wear, high hardness and thermodynamic stability [1,2,3]. The advantageous properties of Al_3Ni reinforced composites can be utilized in a structural material. Various researches were made to produce these Al–Al_3Ni composites by stir casting method, powder metallurgy and mechanical alloying [4,5]. These methods have the problem of obtaining homogeneous distribution of the intermetallic compound in the matrix and fabrication of the complex shaped composites. Hence, in order to avoid these problems, the Al_3Ni particles were in situ formed and homogeneously dispersed in the Al matrix by stirring as well as squeezing. The processing temperature was lower and the stirring time was shorter than those of the conventional vortex method for fabricating ceramics (Al_2O_3, SiC, etc.) reinforced Al matrix composites. Ferguson et al. (2014) investigated the mechanical properties of the reactive stir-mixed and squeeze cast Al/Cu based metal matrix nanocomposites [6]. Hossein Abdizadeh et al. (2014) comparatively studied the metallurgical and mechanical properties of nano MgO reinforced Al composites produced by stir casting and powder metallurgy methods [7]. Weiping Chen et al. (2014) reported that (SiC+Ti) / 7075Al hybrid composites have more strength and plasticity produced by squeeze casting [8]. Abou El-khair et al. (2011) metallurgical, mechanical and thermal properties of squeeze cast SiC, ZrO2 reinforced composites [9]. Mitsuaki Matsumuro et al. (2006) investigated the production of in-situ intermetallic compound by the addition of metal Powders [10]. The present work focuses on the fabrication of AA1100/ Al_3Ni MMC was successfully fabricated using the in-situ method of stirring and squeeze casting. Metallurgical, mechanical and tribological characterization are carried out.

Experimental Procedure

Aluminium alloy 1100 is used as the base metal and nickel powder (<100μm) was used as the reinforcement. Molten Al (99.9 % purity) in a stainless steel container was set in electrical furnace and kept at the desired temperature. Ni powder was added to the molten pure Al by a powder feeder using ultrasonic vibration and then stirred into the melt. The rate of introduction was few grams per minute. Various compositions of reinforcement in AA1100 are made in a stir casting furnace. They are Pure Al, Al with 5% Ni, Al with 10% Ni, Al with 5% Ni (later subjected to squeeze casting), Al with 10% Ni (later subjected to squeeze casting) The temperature was kept at 973 K (when Ni is added) and 1123 was the maximum temperature. The stirring time was about 5 minutes and the stirring speed is 700 rpm and the maximum speed of the stirrer was 850 rpm. Once stir casting is made the molten metal is transformed to squeeze casting for the application of pressure. Mechanical Properties and metallurgical properties are compared to Stir casting (Al 5% Ni, Al 10% Ni) and squeeze casting (Al 5% Ni, Al 10% Ni) and with the Pure Al. Standard metallographic procedures are followed for etching the samples. The optical microscope is used for microstructural analysis. Five specimens of size 25mm x 25 mm were prepared from castings having different content of Ni particles. The X-ray diffraction patterns (XRD) were obtained using analytical X-ray diffractometer with Cu-Ka radiation to confirm the presence of Ni particles. A Brinell hardness testing machine is used for measuring the hardness of the fabricated samples. In Al alloys, 10 mm diameter steel ball with a force of 500 kgf is used. Tensile specimens were prepared as per IS 1608:2005 standard for each content of Ni. The cylindrical specimens of size 10mm diameter and 30 mm height was taken to perform wear test and to calculate wear rate.

Results and Discussion

X-RAY Diffraction analysis.

Figure 2 shows the XRD patterns of the composite fabricated and it reveals the formation of Al_3Ni. The peaks of Al_3Ni are distinctly clear and they decrease with an increase in Al_3Ni content and also the peaks of AA1100 are decreasing. It is evident from the XRD pattern that Al_3Ni is the major phase present along with some traces of Ni without any formation of intermetallic compounds which indicate the thermal stability of in-situ formed Al_3Ni. Non availability of other compounds in significant quantity indicates that the interface between AA1100 and Al_3Ni is free from contamination. Traces of unreacted Ni powder were also found. The pure interface is an important requirement of MMCs to exhibit better mechanical properties as compared to the monolithic alloys.

Microstructural analysis.

Figure 3 (a) shows the microstructure of cast AA1100 alloy. Figure 3 (b, c, d & e) shows the optical micrographs of AA1100 and AA1100-Al3Ni MMC with various percentages of reinforcement. It exhibits a typical dendritic structure of the elongated primary a-Al which is formed due to the super cooling during solidification. Secondary intermetallic phases are seen around the dendrites. The in-situ formed Al_3Ni particles have refined the a-Al grains because Al_3Ni particles offer resistance to the growth of a-Al during solidification [10]. From the microstructure it was observed that the Ni particles are distributed uniformly in the matrix in Particles of varying shapes and sizes [11]. The micrographs confirmed an unreacted Ni phase at the center of the powder and an intermediate Al_3Ni2 phase between the Al_3Ni and unreacted Ni. No other intermetallics were detected. These observations were consistent with a report from the literature on the rate of formation of Ni-Al intermetallic compounds. The Ni powder does not instantly react and change to Al_3Ni as soon as it is added. On the contrary, the reaction with the molten AA1100 gradually proceeds, working inward towards the centre of the Ni powder from the outer surface, and the Al_3Ni particles smaller than the added N powder are dispersed into the matrix as a result of the stirring and squeezing [10]. The effect of wetting between the particles during solidification and melting are extracted to the solidification interface [11].

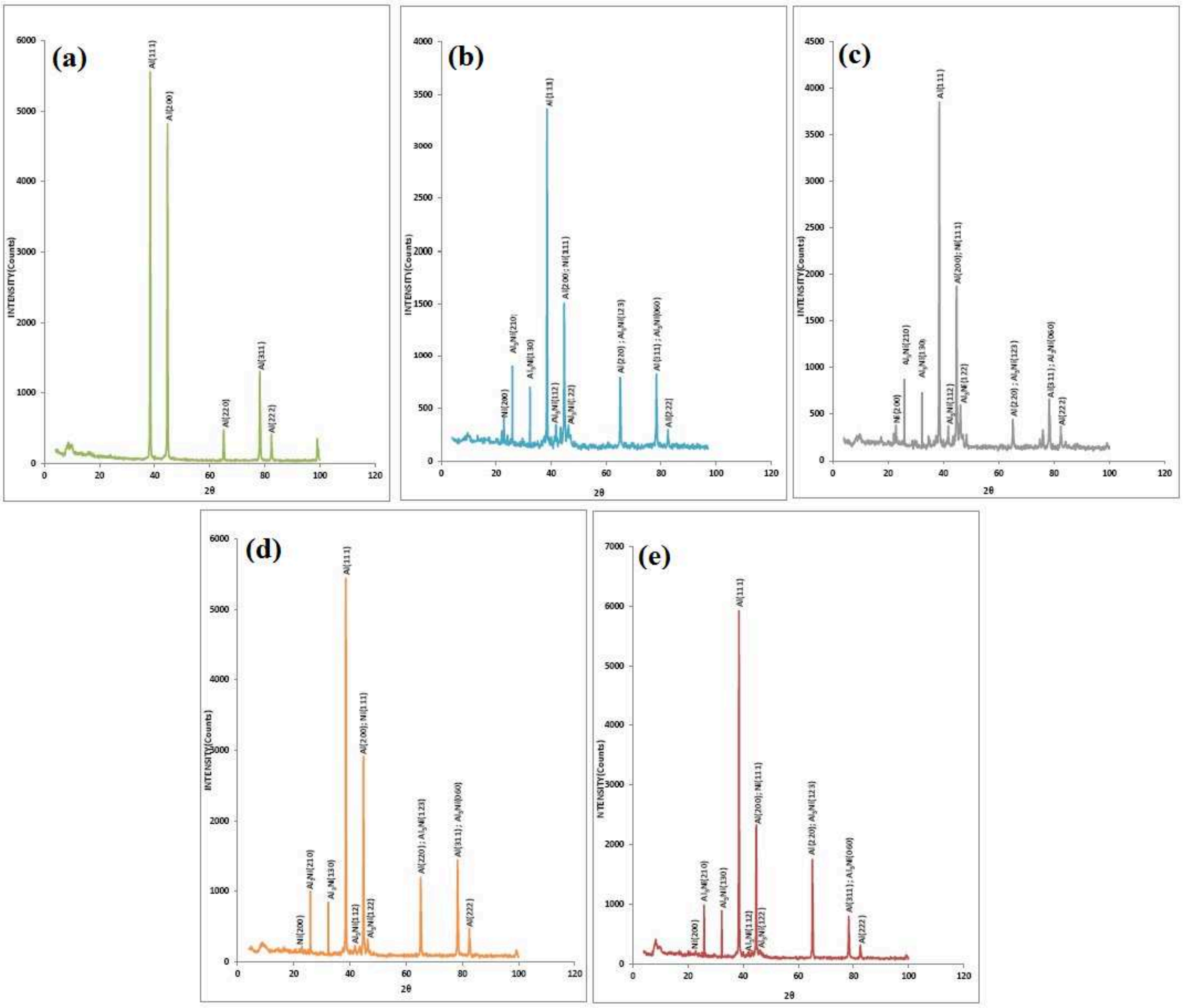

Fig. 2 XRD analysis of (a) Base metal, (b) 5 wt.% Ni stir cast MMC, (c) 5 wt.% Ni squeeze cast MMC, (d) 10 wt.% Ni stir cast MMC, and (e) 10 wt.% Ni squeeze cast MMC

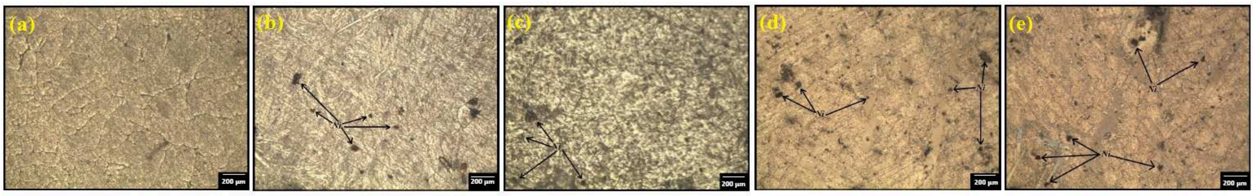

Fig. 3 Microstructure of (a) Base metal, (b) 5 wt.% Ni stir cast MMC, (c) 5 wt.% Ni squeeze cast MMC, (d) 10 wt.% Ni stir cast MMC, and (e) 10 wt.% Ni squeeze cast MMC

Tensile strength.

Table 1 and figure 4 (a) depicts the effect of content of Al_3Ni on the UTS and the effect of stir and squeeze casting. AA1100/10wt. % Al composite (squeeze casting) exhibits 78.18% higher UTS in comparison with AA1100 alloy (UTS-110 MPa) while AA1100/10wt. % Al composite exhibits 30.27% higher UTS.

Table 1 Tensile behavior of Al 1100/10 wt.% Ni MMCs (Stir and Squeeze Casting)

Composition of the MMC	Tensile load (N)	Fractured area (mm^2)	Ultimate tensile strength (Mpa)
Al 1100/10 wt.% Ni MMCs (Stir)	2847.37	19.87	143.30
Al 1100/10 wt.% Ni MMCs (Squeeze)	3910.20	19.95	196.00

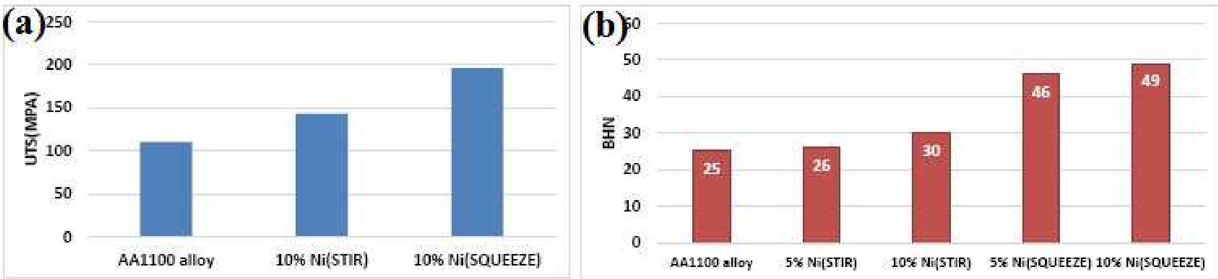

Fig. 4 (a) Tensile strength and (b) Macrohardness of the different samples

The strengthening effect of AA1100 by in-situ formed Al_3Ni particles can be explained as follows. The reinforcement Al_3Ni and matrix material AA1100 have different coefficient of thermal expansion. This variation in thermal expansion between reinforcement and matrix tends to append high density of dislocations around Al_3Ni particles during solidifications [11]. The interaction between Al_3Ni and dislocations strengthen the composites during loading. Increase in content of Al_3Ni results in high interaction which enhances the tensile strength [11]. The distribution of Al_3Ni particles plays aa important role to enchance the tensile strength. Al_3Ni particles does not have any sharp edges, due to this notching effect is reduced and the tensile strength is improved.

Macrohardness Analysis.

Figure 4 (b) shows the effect of content of Al_3Ni on the macro hardness of the fabricated composites. Macro hardness of the fabricated composites increases with the increase in Al_3Ni. AA1100/10wt, % Al_3Ni composites exhibits 42.65% higher macro hardness when compared to AA1100 alloy which may be due to the presence of Al_3Ni in the composites. Hibino et al. (1993) reported that during solidification of cast composites, [11] Al_3Ni particles increase the dislocation density.

Wear Analysis.

The effect of sliding time on wear rate of AA1100/Al_3Ni in-situ composite is depicted in the figure 5 (a & b). The figure shows that the wear rate increases with an increase in sliding distance or the sliding time. The asperity to asperity contacts of the relatively moving counter surfaces initiates the proceedings of sliding wear. The asperities of the counter surface can be considered as sharper and harder during initial wear stage. Those sharp asperities are subjected to higher amount of stress. The stress concentration on sharp asperities increases and in due course they deform plastically. Asperities having a higher degree of sharpness are fractured due to normal and shear stress acting at the contact surface. As a result the wear rate increases with the increase in sliding time. From the graphs, it can be inferred that the squeeze cast MMC has better hardness properties than a stir casted MMC due to the fine microstructure because of unidirectional solidification and proper pre-placement of fibers in the matrix as in the case of squeeze casting.

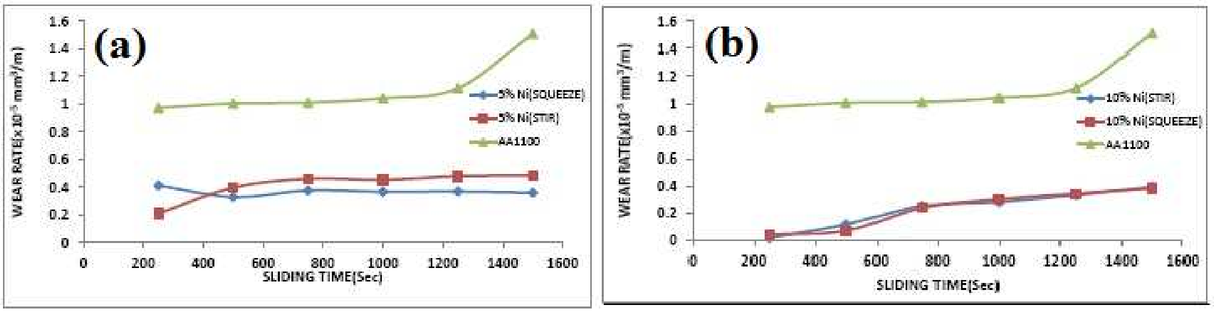

Fig. 5 Wear rate for (a) 5 wt. % MMC (stir & squeeze), and (b) 10 wt. % MMC (stir & squeeze)

Conclusions

AA1100/Al_3Ni MMCs were successfully produced by in-situ reaction of Ni powder and molten alloy AA1100. Optical micrographs and XRD patterns shows the Al_3Ni particles. No intermediate phases were formed due to the thermal stability of Al_3Ni. Ni particles were found to have uniform distribution in the matrix, good bonding and clear interface. Increased content of Al3Ni particles in matrix alloy resulted in higher hardness and ultimate tensile strength of the composites. Maximum improvement in properties was achieved in squeeze casting method with AA1100/10 wt. % Ni MMC which reduced the dry sliding wear rate from 1.5x10-5 mm^3/m (AA1100 alloy) to 0.38x10-5 mm^3/m (AA1100/Al_3Ni MMC) and increased the hardness of 25 BHN (AA1100 alloy) to 49 BHN (AA1100/Al_3Ni MMC). The UTS was increased from 110 Mpa (AA1100 alloy) to 196 Mpa (AA1100/Al_3Ni MMC).

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