FABRICATION OF INTERMETALLIC COMPOUND DISPERSED ALUMINUM MATRIX COMPOSITES BY POROUS NICKEL

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1 Introduction

Aluminum and Aluminum alloy are an important class of materials because of their versatile properties which render them suitable for use in a variety of applications. There has been a constant effort to improve the mechanical properties of Al alloy by various means. Metal matrix composite (MMC) technology is one such method which has become very popular in the past few years. [1]. Aluminum intermetallic compounds are expected to serve as practical materials for their resistance for ware, high hardness and thermodynamically more stable [2]. However, aluminum intermetallic compounds such as Al_3Ni are so brittle that it alone cannot serve as a structural material. Attempts have been made to compensate the brittleness by embedding it in a ductile matrix material [3–5].

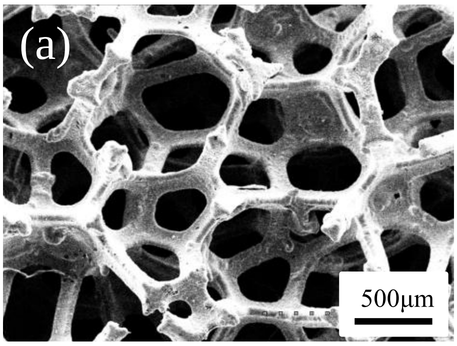
Thus, the advantageous properties of their composites can practically be utilized in a structural material and the ductility of matrix material can avoid its brittle shortcoming. In the past few years, various researches have been made to fabricate these Al–Al_3Ni composites by stir casting method [6], powder metallurgy [7] and mechanical alloying [8].

Their method has the problem with a difficult distribution control of the intermetallic compound in the matrix and to fabricate the complex shaped composites. However, the Al-Al_3Ni composites of the complex shaped can be fabricated by using low pressure infiltration method. Though it is necessary to fabrication nickel as a preform for low pressure infiltration method, in the recently study, there is a low pressure infiltration method which Al is infiltrated to porous nickel [9]. Then Al-Al_3Ni composites can control to fabricate easily by fabricating Al reacts with the porous nickel.

The objective of this paper establishes the optimum manufacturing process of intermetallic reinforced Al alloy composite by using the reaction of porous nickel and Al alloy. Two different cell size of the porous nickel was used the experiment in order to examine the dispersion of the intermetallic compound.

2 Materials and Experiment processes

Matrix in this experiment was used A336 alloy, which composition is Al-12mass%Si-1mass%Ni-1 mass%Cu-1mass%Mg. Reinforcement used in this experiment was porous nickel (Toyama Sumitomo Electric Co., Ltd.). Volume ratio of porous nickel has 16 mass%. Fig.1 shows SEM images of porous nickel. Porous nickel has three-dimensional network structu-



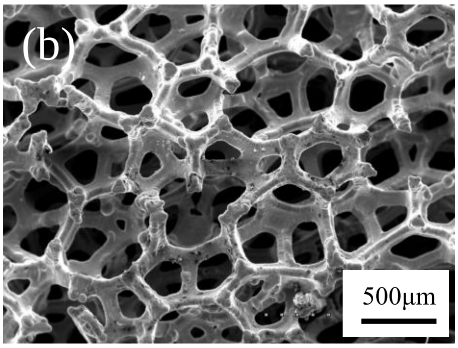


Fig.1. SEM images of porous Ni cell size (a) 0.73-0.98mm, (b) 0.46-0.58mm

Table.1 Properties of porous nickel used in this experiment.

Samples	Cell size [mm]	Volume ratio [mass%]	Thickness [mm]	Specific surface area[m^2/m^3]
Ni	0.73-0.98	14	10	1250
Ni	0.46-0.58	14	5	2800

re like sponge, large surface area and easy to machine. Two kinds with different cell size (0.73-0.98mm, 0.46-0.58 mm) was used the experiment in order to examine the distribution of the intermetallic compound to the matrix. The properties of porous nickel were shows in Table .1. Low pressure infiltration method was used to fabrication of composites. Fabricating conditions was changed temperature of molten alloy and applied pressure. Temperatures of molten alloy were changed from 943K to 1023K under applied pressure of 0.1MPa. Applied pressure was changed from 0.05MPa to 0.15MPa under temperature of molten alloy 973K. Holding time is 10 minutes. Microstructure of composites was observed by Optical Microscope (OM) and Scanning Electron Microscope (SEM). And intermetallic compound was measured the distribution, size and aspect ratio (ratio of length and width). Energy dispersive X-ray spectroscopy (EDX) and an X-ray diffraction analysis (XRD) were used to determine the phase compositions.

3 Results Discussions

3.1Reaction of porous nickel and molten metal

Fig. 2 shows SEM image of porous nickel (cell size: 0.73-0.98mm) reinforced A366 alloy composite.

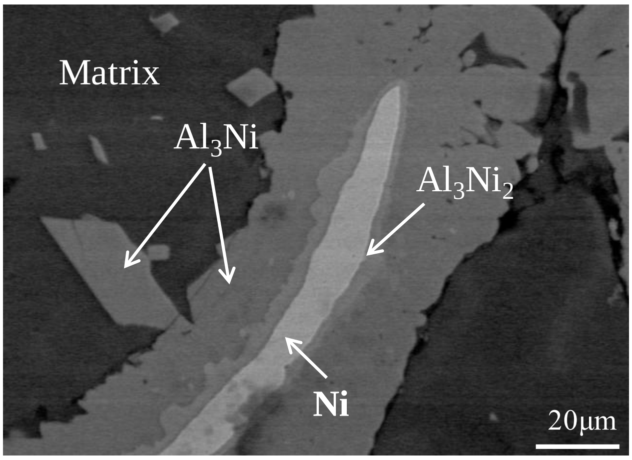


Fig. 2 Reaction between molten Al alloy and porous nickel (cell size: 0.73-0.98mm)

Molten alloy of 973K was infiltrated to porous nickel by using low pressure infiltration of 0.1MPa.

EDX analysis confirmed an Al_3Ni phase, an un-reacted nickel phase at the central section of porous nickel and an intermediate Al_3Ni_2 phase between the Al_3Ni and un-reacted nickel. Other intermetallic compounds were not detected.

The phase formation sequence was described as following equation: [10]

$$3Al + Ni \rightarrow Al_3Ni \text{ -190kJ/mol} \qquad (1)$$

These observations were consistent with a report by Hibino on the rate of formation of Ni-Al intermetallic compounds [11]. As seen in Fig. 2, the porous nickel does not instantly react and change to Al_3Ni. On the contrary, the reaction with the molten alloy gradually proceeds, working inward towards the center of the porous nickel from the outer surface and fine Al_3Ni are dispersed into the matrix. In light of the densities of the Ni, Al_3Ni_2 and Al_3Ni, i.e., 8.9, 4.8 and 4.0 Mg/m^3, [12] respectively, the porous nickel is thought to undergo an expansion reaction with the molten Al. The stress induced by the expansion probably works to the fine Al_3Ni.

3.1 Effect of the applied pressure

Fig. 3 shows microstructure of Al_3Ni/A366 composites (porous cell size: 0.73-0.98mm) by various applied pressure. Temperature of molten alloy was 973K. Molten alloy was infiltrated to the porous nickel under applied pressure of 0.05MPa (Fig. 3(a)). Numerous pores were observed in the composites.

But there are fine Al_3Ni particles uniformly distributed in the aluminum matrix. In the Al_3Ni/A366 composites fabricated under the applied pressure of 0.1MPa (Fig. 3(b)), There is fewer the pores in the Al_3Ni/A366 composites than conditions of applied pressure of 0.05MPa. In addition, it confirmed the fine Al_3Ni particles uniformly distributed in the aluminum matrix. But nickel still remained in the matrix.

In the Al_3Ni/A366 composites fabricated under the applied pressure of 0.15MPa (Fig. 3(c)), the pore doesn't remain in the Al_3Ni/A366 composites.

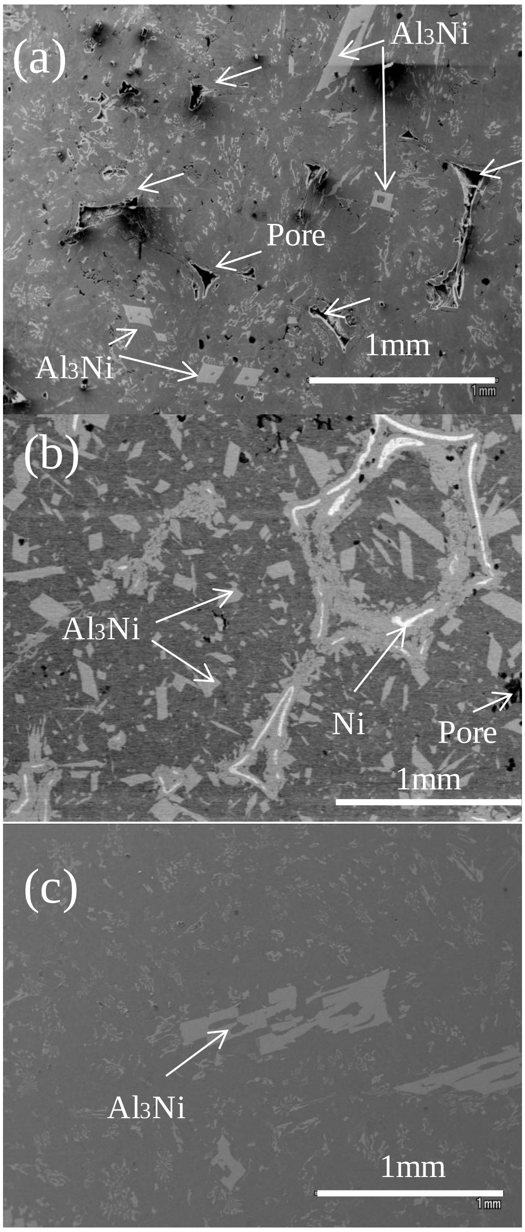


Fig. 3 Microstructure of Al_3Ni/A366 composites by applied pressure (a) 0.15MPa (b) 0.1MPa (c) 0.15MPa

However, porous nickel collapsed by applied pressure of 0.15MPa and it was observed the Al_3Ni a little in the center part of composite. The volume rate of the porous nickel is 6%. Hence, collapse of the porous nickel occurs when the pressure of 0.15 was applied.

3.2 Effect of the molten alloy temperature

Fig. 4 shows microstructure of Al_3Ni/A366 composites (porous cell size: 0.73-0.98mm) by various temperature of molten alloy. Applied pressure was 0.1MPa. All of the porous nickel reacted to Al_3Ni intermetallic compounds. Molten alloy of temperature, 943K was infiltrated to the porous nickel (Fig. 4(a)). Un-reacted nickel phase confirmed in the composite. However, Al_3Ni intermetallic compounds with reacted of Al are dispersed into the matrix and the morphology of Al_3Ni was granular at temperature, 943K.

Molten alloy of temperature, 973K was infiltrated to the porous nickel (Fig. 4(b)). An increase in the temperature of molten alloy led to an increase in the amount of Al_3Ni. The morphology of Al_3Ni was granular and needle-like at 973 K. Un-reacted nickel phase confirmed in the composite. But in the case of molten alloy of temperature 1023K (Fig. 4(c)), Un-reacted nickel phase was not observed in the composite. All of the nickel was occurs the reactions with Al. Al_3Ni with a needle-like and coarse was observed at the molten alloy of temperature 1023K. Thus, the temperature is near liquidus [13]; i.e., 1030K for the Al-14mass%Ni, the target composition. The temperature of the molten Al probably increased above the liquidus locally, however, and the generation of Al_3Ni with a needle-like and coarse morphology probably took place during cooling. Figure 4(c) also shows the increase in the size of the Al_3Ni in parallel with the increasing temperature of molten alloy. [15].

3.3 Effect of cell size of porous nickel

Fig. 5 shows microstructure of Al_3Ni/A366 composites with porous cell size: 0.73-0.98mm (a), 0.46-0.58 mm (b) under fabrication conditions of 973K and 0.1MPa.

As seen in Fig. 5(a), Al_3Ni has been distributed to the matrix and the Al_3Ni not separated from the nickel either was observed. All most of the fine Al_3Ni compounds were homogeneously dispersed. But

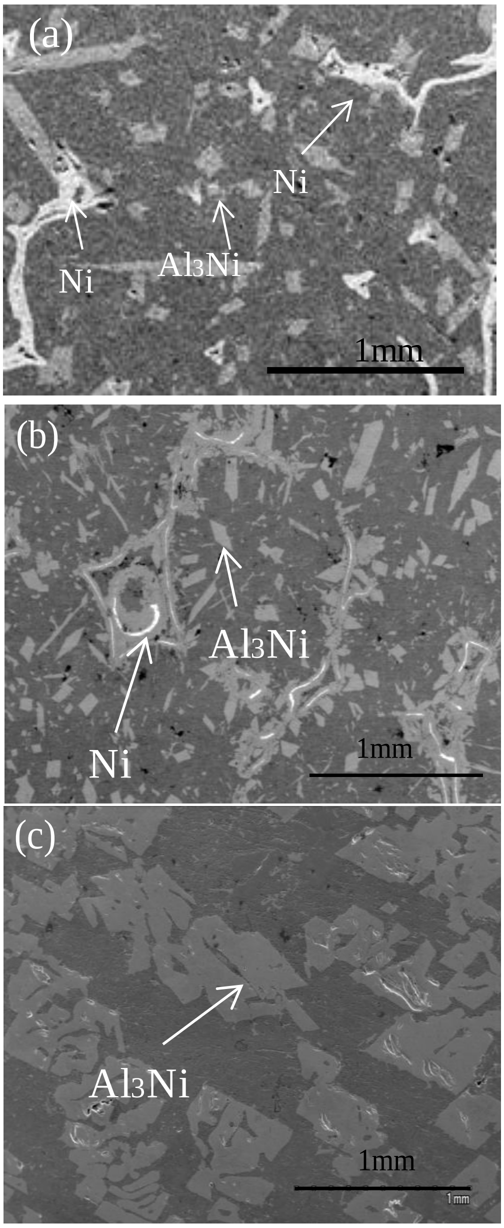


Fig. 4 Microstructure of Al_3Ni/A366 composites of temperature of molten alloy (a) 943K (b) 973K (c) 1023K

shape of the needle-like Al_3Ni was observed too. And numerous pores were observed in the composites.

As seen in Fig. 5(b), All most of fine Al_3Ni are dispersed into the matrix compared with fabricated composite using porous of large cell size.

In light of the specific surface area of the porous nickel (cell size: 0.73-0.98mm) and porous nickel (cell size: 0.46-0.58 mm), i.e., 1250 $m^2/m^3$and 2800 m^2/m^3, respectively, the contact surface with Al increases to the porous nickel of a high specific surface area (2800 m^2/m^3) compared with the porous nickel of a low specific surface (1250 m^2/m^3). Therefore, fine Al_3Ni reacted in the wide region separates from porous nickel and is distributed to the matrix.

Fig. 6 shows results of measuring shape of Al_3Ni in composite with porous nickel cell size: 0.73-0.98mm (a), 0.46-0.58 mm (b) under fabrication conditions of 973K and 0.1MPa. Aspect ratio (ratio of length/width) of Al_3Ni phase was measured.

There are two kinds of Al_3Ni/A366 composite' having the aspect ratio, 3 or less of Al_3Ni (shape of granular) a lot. However, aspect ratio, 3 or more (shape of needle-like) was observed to be had a lot for Al_3Ni/A366 composite with the porous nickel (cell size: 0.73-0.98mm). The Al_3Ni/A366 composite which is used porous nickel (cell size: 0.46-0.58 mm) is expected to improve the mechanical properties.

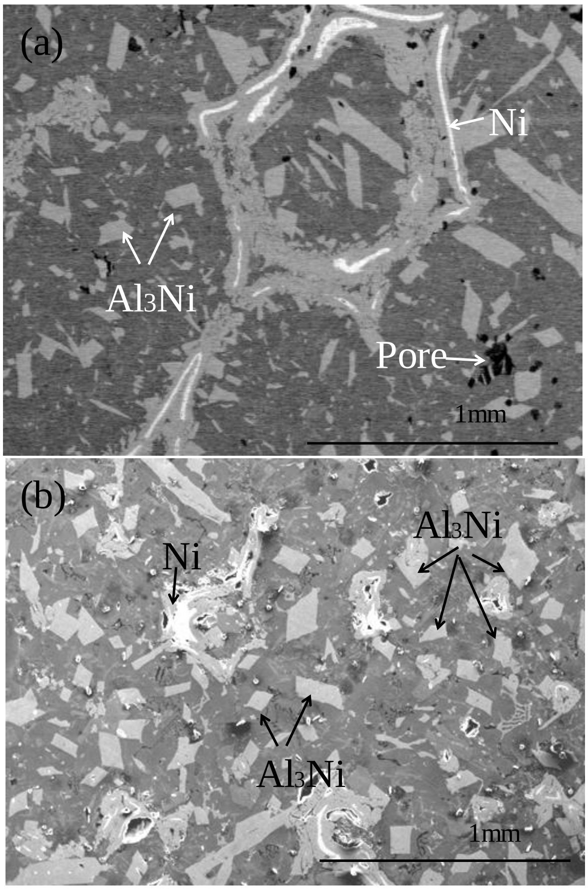


Fig. 5 Microstructure of Al_3Ni/A366 composites with porous cell size : 0.73-0.98mm (a), 0.46-0.58 mm (b) under fabrication conditions of 973K and 0.1MPa

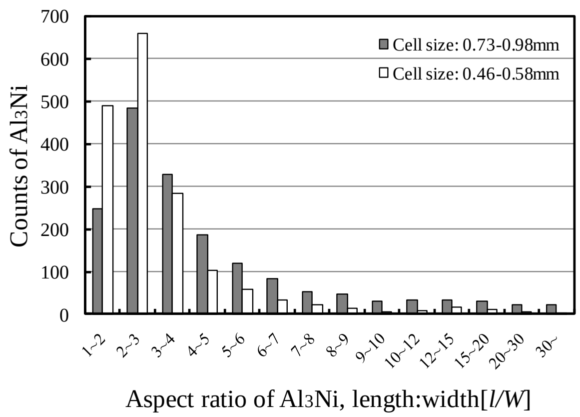


Fig. 6 Aspect ratio (ratio of length/width) of Al_3Ni, porous cell size: 0.73-0.98mm, 0.46-0.58 mm.

4. Conclusions

We have tried new process to propose the fabrication of intermetallic compound reinforced Al alloy matrix composites by the reaction between porous nickel and molten Al alloy. The important results are listed below.

(1) The intermetallic compounds of the reaction of porous nickel with Al alloy produced by low pressure infiltration. Fine and granular Al_3Ni has been distributed in the matrix at the temperature, 973K.

(2) Al_3Ni phase was observed the aspect ratio (ratio of length/width). All most of Al_3Ni has the aspect ratio (1~3) of powdery shape. This morphology is typical of this process and is expected to improve the mechanical properties.

Acknowledgments

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