Development of Intermetallic Compounds Reinforced Al Alloy Composites Using Reaction of Porous Nickel and Aluminum

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A new process is proposed to fabricate an intermetallic compound reinforced aluminum alloy matrix composite using the reaction between porous nickel and molten aluminum. The intermetallic compound reinforced aluminum alloy composite was manufactured with the infiltration process method. Porous nickel reacted with molten aluminum at 1023 K, and the intermetallic compound of Al3Ni was generated on the surface of the porous nickel. The generated intermetallic compound Al3Ni, was delaminated according to the difference of thermal expansion coefficient with nickel, and moves in the direction of aluminum matrix. The effects of processing variables, such as processing temperature, applied pressure and specific surface area of porous nickel on the formation and dispersion behavior of Al3Ni were investigated.

Keywords: porous nickel, composite, intermetallic compound, Al3Ni

1. Introduction

Recently, the conversion to aluminum alloy materials from cast iron materials has been increasing. And advanced features of the aluminum alloy are demanded. The composites which are strengthened with ceramic particles in aluminum alloy are developed. It is applied in practical for brake disk and piston in mobile parts in the industrial field.1,2) Generally, manufacture methods of a ceramic particles dispersed composite include Powder metallurgy process,3) Melting stirring method4) and Casting method,5) etc.

Powder metallurgy process requires high cost. Melting agitating method is the process of using the reactivity of melting aluminum and an additive element to manufacture a reaction product. However, fabrication of a complicated-shaped composite is difficult. Casting method is simple fabrication process to make composite. When wettability of an additive element and aluminum is not good, the dispersibility of particles in matrix is a problem. Moreover, when a composite material is applied as piston head or ring portion by the conventional producing method, it raises many problems.

Whereas, in this research ceramic particles reinforced composite is applied to the piston head and ring portion of piston parts, which is why a development of a new process is purposed. To manufacture intermetallic compound reinforced composite, melted aluminum alloy is infiltrated into porous nickel by applying low-pressure infiltration method. Intermetallic compound is generated by the reaction between aluminum and nickel. This research investigated the generation behavior of the intermetallic compound between aluminum and porous nickel, and the fabrication conditions of the intermetallic compound reinforced composite using low-pressure infiltration method.

2. Materials and Experiment Processes

A336 alloy with composition of Al–12 mass% Si–1 mass% Ni–1 mass% Cu–1 mass% Mg, was used as matrix in this experiment. Preform was porous nickel (Toyama Sumitomo Electric Co., Ltd.). Volume ratio of porous nickel is 4–6%. Figure 1 shows SEM images of porous nickel. Porous nickel has three-dimensional network structure like sponge, large surface area and it is easy to machine. Porous nickel with two different kinds of specific surface areas (a: 1250 mm²/mm³, b: 2800 mm²/mm³) were used in the experiment in order to examine the reactive behavior of the intermetallic compound. The properties of porous nickel were shown in Table 1. Low pressure infiltration method was used to fabricate the composites. Fabricating conditions were altered by changing the temperature of molten Al alloy and

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applying pressure. Temperatures of molten Al alloy were changed from 943 to 1023 K at 0.1 MPa pressure. Applied pressure was changed from 0.05 to 0.15 MPa at 973 K. Holding time is 10 min. Microstructure of the composites was observed by Optical Microscope (OM) and Scanning Electron Microscope (SEM). And the distribution, size and aspect ratio (ratio of length and width) of the intermetallic compounds were measured. Energy dispersive X-ray spectroscopy (EDX) was used to determine the phase compositions.

3. Results Discussions

3.1 Reaction of porous nickel and molten Al

Figure 2 shows SEM images of porous nickel (specific surface area: 1250 mm²/mm³) reinforced A366 alloy composite. Molten Al alloy of 973 K was infiltrated to porous nickel by using low pressure infiltration at 0.1 MPa. EDX analysis confirmed the existence of Al₃Ni phase, nickel phase at the central section of porous nickel and an Al₃Ni₂ phase between the Al₃Ni and nickel. Other intermetallic compounds were not detected. The phase formation sequence was described as following equation:

$$3\text{Al} + \text{Ni} \rightarrow \text{Al₃Ni} - 190 \text{kJ/mol}$$

These observations were consistent with the report by Hibino on the rate of formation of Ni–Al intermetallic compounds. As seen in Fig. 2, the porous nickel does not instantly react and change to Al₃Ni. On the contrary, the reaction between the molten Al alloy and porous nickel gradually proceeds, working towards the center of the porous nickel from the outer surface and fine Al₃Ni are dispersed into the matrix.

In light of the densities of the Ni, Al₃Ni₂, and Al₃Ni, i.e., 8.9, 4.8 and 4.0 kg/m³, the porous nickel is thought to undergo an expansion reaction with the molten Al alloy.

3.2 Effect of the applied pressure

Figure 3 shows microstructure of Al₃Ni/A366 composites (specific surface area: 1250 mm²/mm³) fabricated at various applied pressure. Temperature of molten Al alloy was 973 K.
Molten Al alloy was infiltrated to the porous nickel at applied pressure of 0.05 MPa (Fig. 3(a)). Numerous pores were observed in the composites. But there are fine Al3Ni particles uniformly distributed in the aluminum matrix. In the Al3Ni/Al366 composites fabricated at the applied pressure of 0.1 MPa (Fig. 3(b)). There are less pores in the Al3Ni/Al366 composites than those in the composite infiltrated at applied pressure of 0.05 MPa. In addition, it is confirmed that the fine Al3Ni particles uniformly distributed in the aluminum matrix. But nickel still remained in the matrix. In the Al3Ni/Al366 composites fabricated at the applied pressure of 0.15 MPa (Fig. 3(c)), the pore doesn’t remain in the Al3Ni/Al366 composites. However, it was observed that there was a large size Al3Ni in the center part of composite. Since the volume fraction of porous nickel is 4–6 vol% and ductile material as a reason. It thinks that deformation of porous nickel occurred by applied pressure of 0.15 MPa.

### 3.3 Effect of the molten Al alloy temperature

Figure 4 shows microstructure of Al3Ni/Al366 composites (specifc surface area: 1250 mm²/mm³) fabricated at various temperature of molten Al alloy. Applied pressure was 0.1 MPa. All of the porous nickel reacted with Al alloy to form Al3Ni intermetallic compounds. Molten Al alloy of temperature 943 K was infiltrated to the porous nickel (Fig. 4(a)). Un-reacted nickel phase was confirmed in the composite. However, Al3Ni intermetallic compounds reacted with Al alloy are dispersed into the matrix and the morphology of Al3Ni was granular at temperature 943 K.

Molten Al alloy of temperature, 973 K was infiltrated to the porous nickel (Fig. 4(b)). An increase in the temperature of molten Al alloy led to an increase in the amount of Al3Ni. The morphology of Al3Ni was granular and needle-like at 973 K. Un-reacted nickel phase was confirmed in the composite. But in the case of molten Al alloy of temperature 1023 K (Fig. 4(c)), Un-reacted nickel phase was not observed in the composite. All of the nickel reacted with Al. Coarse Al3Ni with a needle-like shape was observed at the molten Al alloy of temperature 1023 K. Thus, the temperature is near liquidus.9) The temperature of the molten Al probably increased above the liquidus locally, however, and the generation of Al3Ni with a needle-like shape and coarse morphology probably formed during cooling. Figure 4(c) also shows the increase of the size of the Al3Ni in parallel with the increasing temperature of molten Al alloy.10)

### 3.4 Effect of cell size of porous nickel

Figure 5 shows microstructure of Al3Ni/Al366 composites with specific surface area: (a) 1250 mm²/mm³, (b) 2800 mm²/mm³ under fabrication conditions of 973 K and 0.1 MPa. As seen in Fig. 5(a), all most of the fine Al3Ni compounds were homogeneously dispersed. But shape of the needle-like Al3Ni was observed too. And numerous pores were observed in the composites.

As seen in Fig. 5(b), all most of fine Al3Ni are dispersed into the matrix compared with fabricated composite using porous nickel with large cell size. In light of the specific surface area of the porous nickels, i.e., 1250 and 2800 mm²/mm³, the contact surface of the porous nickel of a high specific surface area (2800 mm²/mm³) is higher than that of the porous nickel of a low specific surface (1250 mm²/mm³).

Figure 6 shows results of measuring shape of Al3Ni in the composite with specific surface area of: (a) 1250 mm²/mm³, (b) 2800 mm²/mm³ under fabrication conditions of 973 K and 0.1 MPa. Aspect ratio (ratio of length/width) of Al3Ni phase was measured.
There are two kinds of Al₃Ni/A366 composite having the aspect ratio, 3 or less of Al₃Ni (shape of granular) a lot. However, aspect ratio, 3 or more (shape of needle-like) was observed having a lot for Al₃Ni/A366 composite with the porous nickel (specific surface area: 1250 mm²/mm³).

4. Conclusions

New process is proposed to fabricate 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 formed by the reaction of porous nickel with Al alloy are produced by low pressure infiltration. Fine and granular Al₃Ni has been distributed in the Al alloy matrix at the temperature 973 K and applied pressure 0.1 MPa. As for the particle-shape of the intermetallic compound, when specific surface area of porous nickel became larger, more fined intermetallic compound was generated. The amount of intermetallic compound increased with increasing contact area of porous nickel with aluminum alloy.

(2) Al₃Ni was observed the aspect ratio, 3 or less of Al₃Ni. Most of Al₃Ni has the aspect ratio (1–3) of particulate shape. The reaction of porous nickel and Al alloy was fabricate particle-shaped intermetallic compound reinforced composite.

REFERENCES

8) JCPDS: International centre for diffraction data, 4-0850, 14-0648, 2-0416.