EXPERIMENTAL PROCEDURE

The powders of $Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$ were produced by a high-pressure gas atomization technique. The gas used for the atomization was nitrogen and the applied pressure was 4 MPa. The atomized powders were sieved and the powders below 45 μm were used for extrusion. Subsequently, the powders were compacted in an aluminum capsule with a diameter of 41 mm and degassed in a vacuum chamber. The compact billets were extruded into the cylindrical bar of 13 mm diameter with a reduction ratio of 10:1. Tensile properties of the as-extruded bulks were determined at temperatures between room temperature and 673K using an Instron-type tensile testing machine. The initial strain rate was $2.1 \times 10^{-3}\ s^{-1}$. The structure of the powders and as-extruded bulks was examined by X-ray diffraction and transmission electron microscopy techniques. Fatigue strength and coefficient of thermal expansion(α) were measured using a rotating bending machine and a dilatometer, respectively. The specific wear resistance against SKS3 was also evaluated at room temperature by the pin-on disc method.

RESULTS AND DISCUSSION

The structure of the as-atomized powders and as-extruded alloy consists of Al, Al_3Ni and $Al_{11}(Ce, La)_3$ phases. Figure 1 shows the bright-field electron micrographs of the as-atomized powder and as-extruded alloy. It is seen that the powder consists of a nanocrystalline structure with a grain size of about 10 nm (Fig.1, a). On the other hand, the as-extruded alloy has a finely mixed structure consisting of intermetallic compounds dispersed homogeneously in an aluminum matrix (Fig.1, b). The aluminum matrix in the alloy has a grain size of 100 to 150 nm and the intermetallic compounds are composed of Al_3Ni and $Al_{11}(Ce, La)_3$ with particle sizes of 10 to 100 nm. The volume fraction of their intermetallic compounds is measured to be about 30 %.

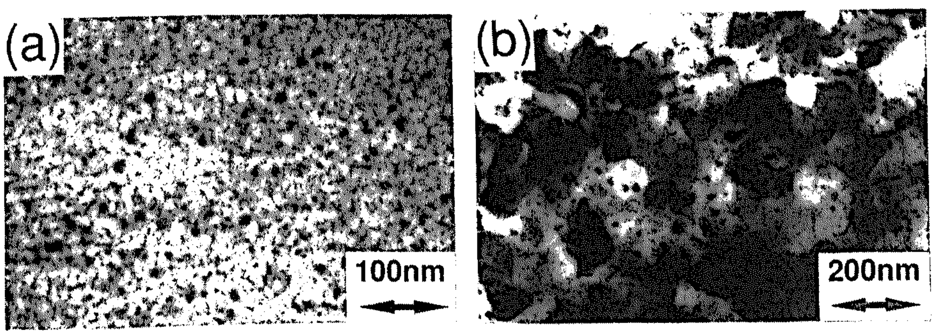

Figure 1. TEM micrographs of $Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$ powder (a) and extruded alloy (b)

It is expected that a low coefficient of thermal expansion is obtained for the extruded $Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$ alloy because of the precipitation of a large amount of Al_3Ni and $Al_{11}(Ce, La)_3$ compounds. Table I summarizes the coefficient of thermal expansion (α) of the Al-Ni-Mm-Zr alloy in the temperature range of 423 to 473K, along with the data for the A6061 and A5056 alloys. The α value is about 20% smaller than those for the conventional Al-Mg-Si and Al-Mg alloys.

Table I. Coefficients of thermal expansion of an extruded $Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$ alloy and conventional aluminum alloys

Alloys	**Coefficient of thermal expansion (423 - 473K) ($\times 10^{-6}$ K^{-1})**
$Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$	**19.9**
6061	**24.4**
5056	**25.4**

Tensile strength (σ_{UTS}), Young's modulus (E), elongation (ε_P) and Vickers hardness (Hv) at room temperature of the as-extruded alloy are summarized in Table II, along with the data of other alloys. The specific strength (σ_{UTS} / ρ) and the specific Young's modulus (E / ρ) are also evaluated in Table II.

Table II. Mechanical properties of an extruded $Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$ alloy and other alloys

Alloys	σ_{UTS} MPa	ε_P %	E GPa	Hv	σ_{UTS}/ρ MPa/Mg · m^{-3}	E/ρ GPa/Mg · m^{-3}
$Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$	830	4.6	100	232	258	31
7075-T6	573	11	72	173	205	26
Ti-6Al-4V	1167	7	113	365	263	26

σ_{UTS} and E of the extruded $Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$ alloy are as high as 830 MPa and 100 GPa, respectively, at room temperature which are much higher than those (σ_{UTS}=573 MPa, E=72 GPa) for the A7075 alloy. Furthermore, the specific strength (σ_{UTS} / ρ) of the $Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$ alloy is 258 MPa/Mg·m^{-3}, which is about 25 % higher than that of the high specific strength aluminum alloy (A7075). The specific strength value is almost comparable to that for the Ti-Al-V alloy. In addition, the specific Young's modulus (E / ρ) of the $Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$ alloy is much higher than those of A7075 and Ti-6Al-4V alloys. Figure 2 shows the temperature dependence of the tensile strength for the $Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$ alloy. The strength was measured after holding for 1 h at each testing temperature. Tensile strength values at 373 and 473 K are as high as 678 and 446 MPa, respectively. Thus, the $Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$ alloy is attractive as a heat resistance aluminum alloy below 473 K. The achievement of the good elevated temperature strength and high Young's modulus is presumably because of the formation of the finely mixed structure consisting of a large amount of Al_3Ni and $Al_{11}(Ce, La)_3$ compounds homogeneously embedded in an aluminum matrix which cannot be obtained by conventional thermo-mechanical treatments.

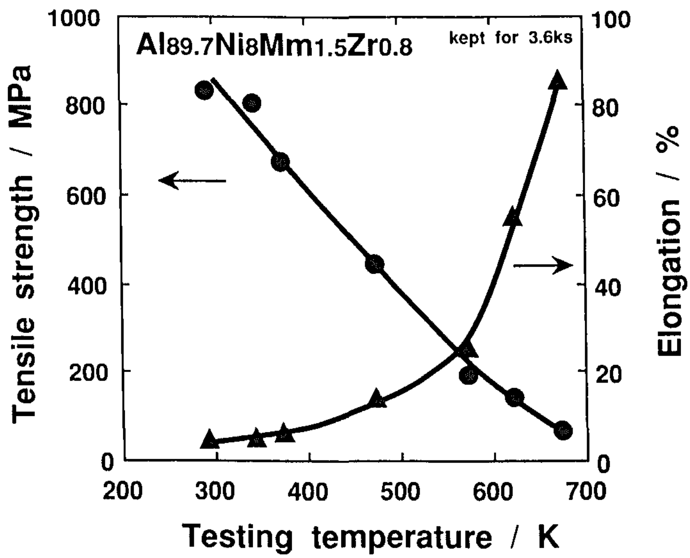

Figure 2 Temperature dependence of tensile strength for an extruded $Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$ alloy

Fatigue strength is also an important property in practical use. Figure 3 shows the fatigue strength of the extruded $Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$ alloy at room temperature and 473 K measured by the rotating bending method. The fatigue strength after the cycle of 10^7 is as high as 372 MPa at room temperature which is 1.4 times as high as the highest value for conventional Al-based alloys. Similarly, the fatigue strength after the cycle of 10^7 at 473 K is 200 MPa. Also, the fatigue ratio defined by the ratio of the fatigue strength after the cycle of 10^7 to the tensile strength (σ_{UTS}) is 0.45 at room temperature and 473 K. It is therefore concluded that the fatigue strength of the as-extruded $Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$ alloy is much superior to those for the conventional aluminum alloys.

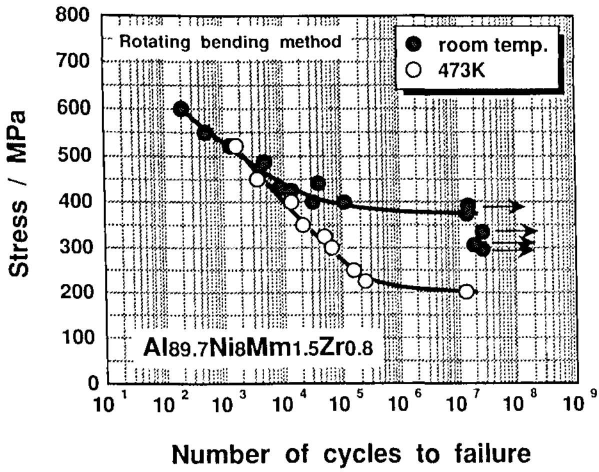

Figure 3 S-N curve of an extruded $Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$ alloy

When a material is used as a machinery part, wear resistance is also an important property to determine the operation span of the machinery. Table III summarized the results of specific wear resistance in the condition where an applied stress is 1 MPa and the sliding velocity is 1.25 m/s, along with the data for conventional A7075 and Al-20mass%Si powder metallurgy alloy. The wear resistance of the $Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$ alloy is about 40 % smaller than that for the Al-20mass%Si alloy developed for wear resistance. It is thus concluded that the $Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$ alloy has the good wear resistance as well as the high tensile strength, high fatigue strength and the low coefficient of thermal expansion.

Table III Wear resistance of an extruded $Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$ alloy and other aluminum alloys

Alloys	Specific wear (x $10^{-7}mm^2$/ kgf)
$Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$	5.9
Al-20mass%Si	9.6
7075-T6	8.7

Testing condition Pin : SKS3, Pin diameter : 7.98, Load : 98N
Sliding velocity : 1.25m/s, Lubricant : dry

CONCLUSION

The microstructure and mechanical properties were examined for the $Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$ alloy produced by extruding atomized nanocrystalline powders. The alloy exhibited fine structure consisting of Al_3Ni and $Al_{11}(Ce, La)_3$ with particle sizes ranging from 10 to 100 nm dispersed homogeneously in an aluminum matrix with grain sizes of 100 to 150 nm. The tensile strength values at room temperature and 473 K are as high as 830 and 446 MPa, respectively. The fatigue strength after the cycle of 10^7 is also as high as 372 MPa at room temperature and 200 MPa at 473 K. In addition, the alloy exhibits a low coefficient of thermal expansion and good wear resistance because of the homogeneous dispersion of a large amount of the intermetallic compounds. The simultaneous achievement of good mechanical properties allows to expect practical uses of the new type aluminum alloys in various fields.

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