EFFECT OF MATRIX AND REINFORCEMENT MORPHOLOGY ON MECHANICAL PROPERTIES OF AL/TINI SHAPE MEMORY COMPOSITE

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SUMMARY: Metal matrix composites reinforced with shape memory alloys induce compressive residual stress in the matrices resulting in improved tensile properties of the composite. In the present study, Al/TiNi shape memory composites were fabricated by squeeze casting and powder metallurgy method so called Plasma Activated Sintering(PAS). Fairly good matrix/reinforcement bonding was observed in the Al/TiNi composites. The effects of residual stress caused by the shape recovery force have been compared as a function of reinforcement volume fraction, prestrain, matrix strength and reinforcement shape. Strengthening effect due to TiNi reinforcement as well as compressive residual stress was investigated. It was found that the yield strength of the composites increased with increasing the volume fraction of TiNi reinforcement and the amount of prestrain applied to the composite. Moreover, the percentage of strength increment of pure continuous fiber Al/TiNi(Al/TiNi$_{cf}$) composite caused by prestrain was higher than that of AC4A Al/TiNi$_{cf}$ composite.

KEYWORDS: squeeze casting, plasma activated sintering, interfacial bonding, compressive residual stress, shape memory effect, Al/TiNi composite

INTRODUCTION

Aluminum alloy metal matrix composites reinforced with ceramic fibers have good properties such as low specific gravity, high specific strength and high stiffness. They are being expected as materials of automotive parts because of their good wear resistance and high temperature properties [1-2]. These potential materials, however, have demerits such as the interfacial weakness due to their poor chemical attraction and wettability between the metal matrices and ceramic reinforcements. Moreover, tensile strength and mechanical properties of composite are deteriorated by the tensile residual stress in the matrix that is caused by the thermal expansion coefficient (CTE) mismatch between metal matrix and ceramic reinforcement during the cooling process. Therefore, in the present study, shape memory composite (SMC:Al/TiNi) was chosen to solve problems of metal/ceramic composites. Recovery force of prestrained shape memory alloys upon heating above austenite finish temperature (A_f) gives compressive residual stress in the matrix and it can improve mechanical properties of composite and it will help to close the existing crack [3-7].

Al/TiNi composite can be fabricated by powder metallurgy or casting method [8-9]. In this study, Al/TiNi shape memory composite was fabricated by squeeze casting and plasma activated sintering which is one of the powder metallurgy. The interface between Al matrix and TiNi reinforcement of fabricated shape memory composites was analyzed using SEM and EDX. Tensile tests of Al/TiNi shape memory composite were carried out to characterize the shape memory effect in SMC.

EXPERIMENTAL

Fabrication of $Al/TiNi_{cf}$ shape memory composite

AC4A Al was chosen as matrix because of its good castability, strength and corrosion resistance under high pressure. Pure Al was also used matrix for comparative material. Diameter of 0.3μ TiNi wire was chosen as reinforcement because of its large shape memory effect and high stiffness. The volume fraction of reinforcement was 2-4%. To get off the oxidation film on TiNi wire, the preform was acid cleaned for 240 second in 95% CH_3COOH+ 5%HF bath(60øC). Squeeze casting was carried out by pouring molten Al of 750øC into the TiNi preform, which was placed in the mold preheated to 400øC, and then by applying pressure of 75.. In applying pressure, delay time and duration time were 7 and 60 seconds, respectively. The direction of applied pressure was perpendicular to longitudinal direction of TiNi wire. The squeeze cast block was quenched into water after applying.

Fabrication of $Al/TiNi_p$ shape memory composites

Pure Al powder(average dia.:20μ, purity:99.9%) was selected as the matrix for the composites and average diameter of 45μ TiNi powder was chosen as reinforcement. $Al/TiNi_p$ shape memory composite was fabricated by plasma activated sintering. Figure 1 shows schematic illustration of plasma activated sintering equipment. Plasma activated sintering is the sintering method of passing pulse current for ignition and after that, passing direct current to maintain heat. Aiming volume fraction of TiNi reinforcement in as-fabricated $Al/TiNi_p$ was determined 3, 5 and 8%. Utilizing image analyzer (LECO E001), the volume fraction of TiNi reinforcement in the as-fabricated composite was investigated and compared with the aiming volume fraction.

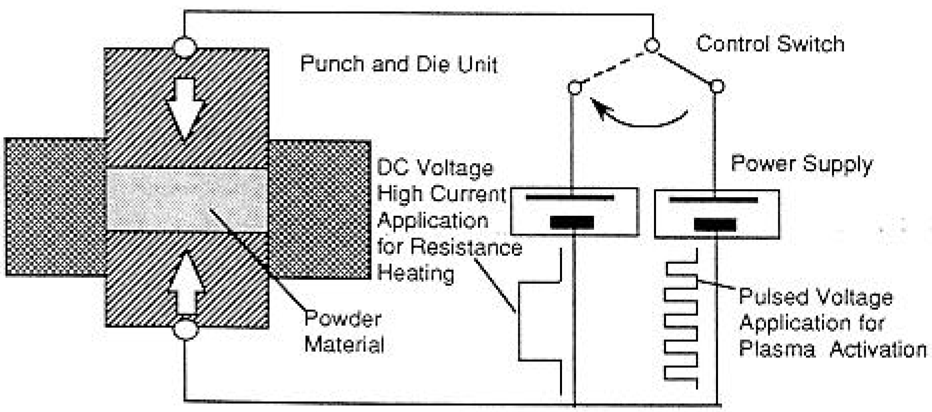

Fig. 1: Schematic illustration of PAS equipment

Microstructure and tensile test

Microstructure of Al/TiNi shape memory composite was examined and analyzed with optical microscope and SEM (JEOL JSM5400) and diffusion distance of major elements at Al/TiNi interface was checked with EDX analysis. Transformation temperatures of TiNi wire which was aged at 500øC for 210 minutes followed by water quenching to induce martensitic transformation of TiNi fiber were measured using differential scanning calorimeter(DSC) with a heating rate of 10øC/min. to decide the temperature of tensile testing. Tensile specimens of composites were machined by electro-discharge method. Tensile specimens were heat treated for shape memorizing at 500øC for 210 minutes followed by water quenching to induce martensitic transformation. Composites with martensitic TiNi reinforcement were prestrained up to 4% elongation. Tensile tests were carried out at 90øC(above A_f) with strain rate of 1mm/min..

RESULTS AND DISCUSSION

Microstructure

Figure 2 is the optical micrograph of the Al/TiNi shape memory composite. The marking of A and B in figure represents TiNi reinforcement and Al matrix, respectively. Fine microstructures, which have no manufacturing defect in Al matrix and the matrix/ reinforcement interface, are obtained. In Figure 2(a), matrix is a typical Al-Si cast microstructure that consists of eutectic structure around the primary ϕ. It is considered that TiNi is not act as nucleation site because matrix/reinforcement interface is mainly composed of eutectic structure with few primary ϕ which is nucleated at high temperature. After shape memorizing heat treatment, SEM-EDX analysis was carried out in order to identify the diffusion distance of each element at Al/TiNi interface. Squeeze cast Al/$TiNi_{cf}$ composite infiltrated by the pressure of 75. with pouring temperature of 750øC was subjected to heat treatment at 500øC for 210 minutes. Al was diffused by 1.1% from Al matrix to TiNi reinforcement in squeeze cast AC4A Al/$TiNi_{cf}$ composite and this specimen showed fairly good pull-out strength. In pure Al/$TiNi_p$ composite, Al was diffused by 1.2% from Al matrix to TiNi particle. It is considered that Al/$TiNi_p$ composite has a good interfacial bonding because the diffusion distance is similar to the squeeze cast AC4A Al/$TiNi_{cf}$ shape memory composite, which showed a good interfacial bonding by pull-out test.

Tensile property of Al/$TiNi_{cf}$ composite

The transformation temperature (martensite-austenite) and tensile property of shape memory alloy have been reported to change with the condition of shape-memorizing heat treatment [10-13]. Accordingly, transformation behavior of TiNi alloy must be ascertained in advance to evaluate tensile properties of Al/TiNi composites. Austenite finish temperature of TiNi aged at 500øC for 210 minutes was 57.7øC from the result of DSC analysis.

Figure 3 is the tensile test results of squeeze cast Al/$TiNi_{cf}$ composite with and without prestrain. The volume fraction of TiNi reinforcement is 2.5% and 3.2% in as-fabricated composite. Pure Al/2.5%$TiNi_{cf}$ and pure Al/3.2%$TiNi_{cf}$ composites without prestrain exhibit the strength increment of 11 and 15., respectively, by fiber strengthening. From this result, it is found that the yield strength of the composite is increased with increasing the volume

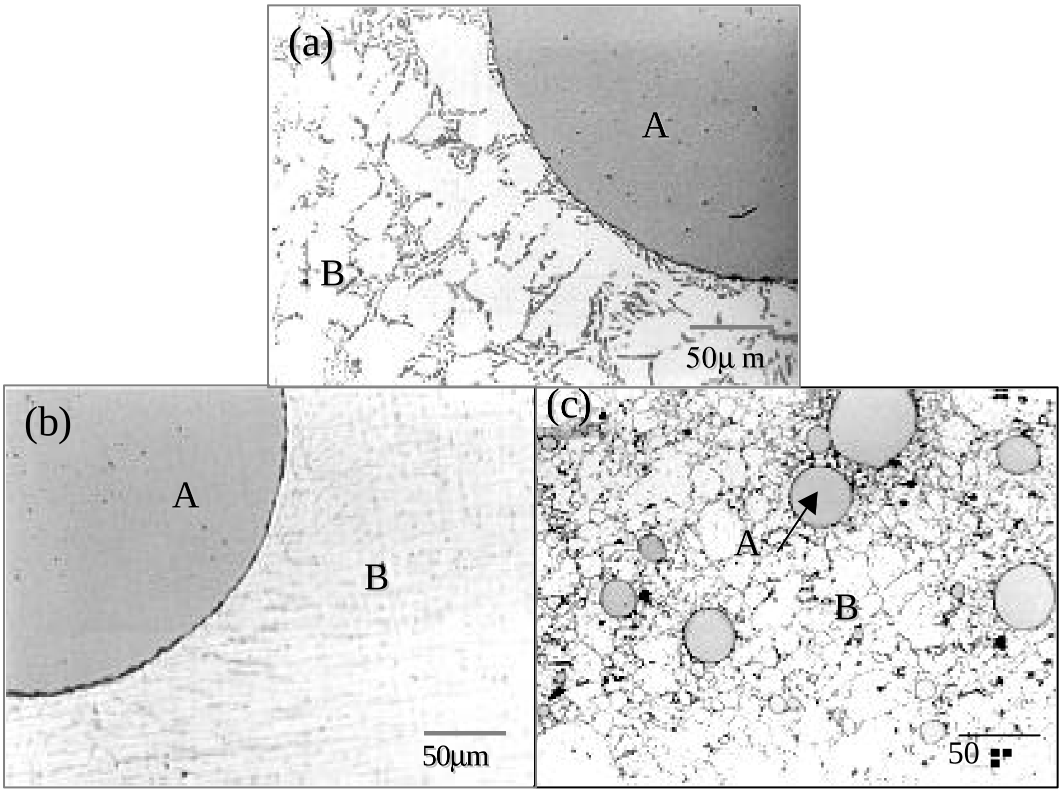

Fig. 2: Optical micrographs of Al/TiNi composite
(a) AC4A Al/TiNi$_{c.f}$ composite (b) Pure Al/TiNi$_{c.f}$ composite (c) Pure Al/TiNi$_{P}$ composite

fraction of TiNi reinforcement. The yield strength of pure Al/2.5%TiNi$_{c.f}$ and pure Al/3.2%TiNi$_{c.f}$ composite is increased 16% and 20%, respectively, by applying 4% prestrain. This is caused by the compressive residual stress due to the shape recovery force of TiNi reinforcement. The tensile test results of squeeze cast AC4A Al/3.2%TiNi$_{c.f}$ composite is also shown in Figure 3. The amount of improved strength by TiNi fiber reinforcement and shape memory effect is 18% and 38%, respectively.

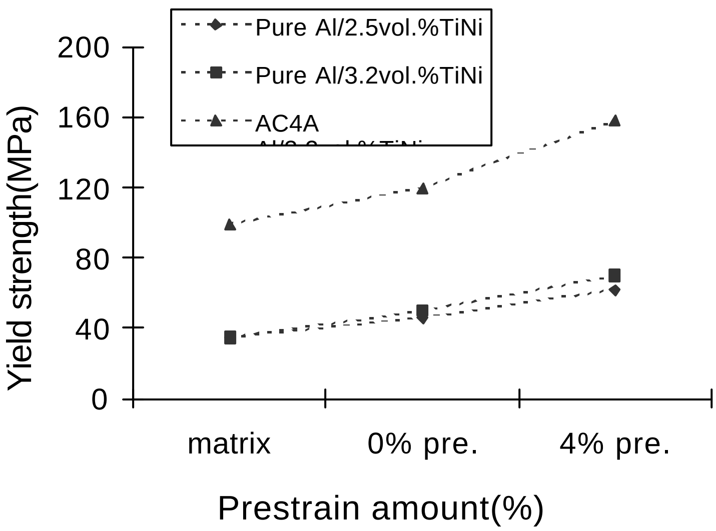

Fig. 3: The results of tensile test in squeeze cast Al/TiNi$_{c.f}$ composite

Figure 4 shows the percentage of strength increment induced by shape recovery force with 4% prestrain in pure Al/TiNi$_{cf}$ composites and AC4A Al/TiNi$_{cf}$ composite. Yield strength increment induced by shape recovery force with 4% prestrain is 32% in AC4A Al/3.2%TiNi$_{cf}$ composite, 34% and 40% in pure Al/2.5%TiNi$_{cf}$ and pure Al/3.2%TiNi$_{cf}$ composite, respectively. In the same volume fraction of the reinforcement(3.2%), the strength increment of pure Al composite is higher than that of AC4A Al composite. These differences in strength increment of the composites might be mainly caused by the strength of their matrix.

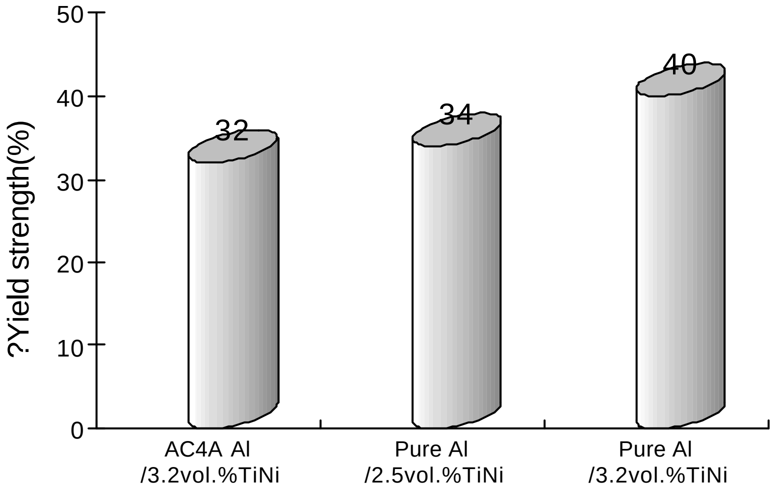

Fig. 4: Comparison of yield strength increment induced by shape recovery with 4% prestrain between pure Al/TiNi$_{c.f}$ composites and AC4A Al/TiNi$_{c.f}$ composite

Tensile property of Al/TiNi$_P$ composite

Figure 5 shows the tensile test results of pure Al/TiNi$_P$ shape memory composites with and without prestrain. Pure Al/3%TiNi$_P$, Al/5%TiNi$_P$ and Al/8%TiNi$_P$ composites without prestrain exhibited the yield strength increment of 11, 17 and 23%, respectively, by particle strengthening in comparison with Al matrix. The yield strength of pure Al/3%TiNi$_P$ composite is increased 15.5 and 21.2. by applying 2 and 4% prestrain, respectively. This is caused by the compressive residual stress due to the shape recovery force of TiNi reinforcement. The yield strength of pure Al/5%TiNi$_P$ and Al/8%TiNi$_P$ composites is also increased with the amount of prestrain.

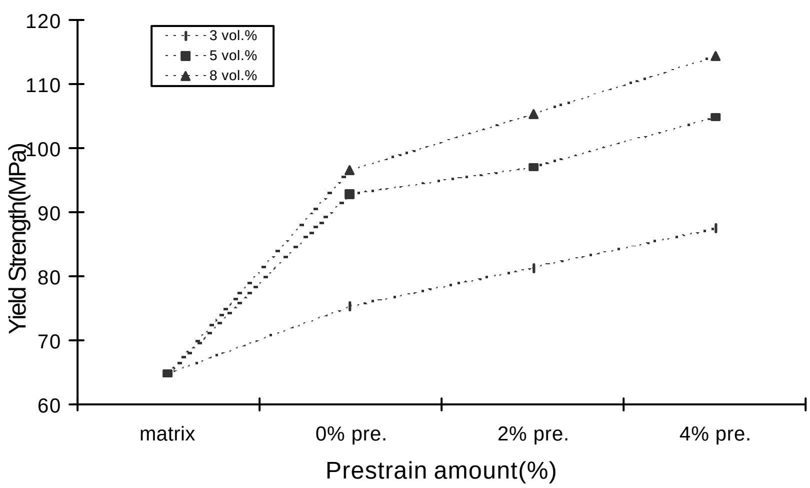

Fig. 5: The results of tensile test in Al/TiNi$_p$ composite

CONCLUSION

In this study, Al/TiNi shape memory composites having a fine microstructure and good interfacial bonding between matrix and reinforcement was successfully fabricated by squeeze casting and plasma activated sintering method. The composite was subjected to 0% - 4% prestrain at room temperature to induce compressive residual stress and then tensile test of the composite was carried out at 90ØC. Yield strength of the composite was increased with increasing the volume fraction of TiNi reinforcement by fiber strengthening and the amount of prestrain by compressive residual stress applied to the composites. The percentage of strength increment of pure Al/TiNi$_{cf}$ composite was higher than that of AC4A Al/TiNi$_{cf}$ composite. These differences in strength increment of the composites might be mainly caused by the strength of their matrix

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REFERENCES

1. I.M.Park and N.J.Kim, “Developments in Metal Matrix Composites for Automotive Parts”, *Journal of Korea Society of Automotive Engineers*, Vol. 16, No. 3, 1994, pp. 37-44.
2. W.J.Park, I.M.Park and N.J.Kim, “Development in Light Weight Metals for Automotive Application”, *Journal of Korea Society of Automotive Engineers*, Vol. 16, No. 4, 1994, pp.23-31.
3. CRAIG A. ROGERS, “Intelligent Material Systems-The Dawn of a New Materials Age”, *Journal of Intelligent Material Systems and Structures*, Vol. 4, 1993, pp. 4-12.
4. Y.Furuya, A.Sasaki and M.Taya, “Enhanced Mechanical Properties of TiNi Shape Memory Fiber/Al Matrix Composite”, *Materials Transactions, JIM*, Vol. 34, No. 3, 1993, pp. 224-227.
5. W.D.Armstrong and H.Kino, “Martensitic Transformations in a NiTi Fiber Reinforced 6061 Alminum Natrix Composite”, *Journal of Intelligent Material Systems and Structures*, Vol. 6, 1995, pp. 809-816.
6. B.S.Kim, Y.S.Cho, I.D.Choi, D.M.An, K.M.Cho and I.M.Park, “Fabrication and Characterization of Squeeze Cast AC4A Al/TiNi Shape Memory Composites”, *Journal of the Korean Institute of Metal and Materials*, Vol. 35, No. 10, 1997, pp. 1359-1365.
7. B.S.Kim, C.H.Han, I.D.Choi, I.M.Park and D.M.An, “Characterization of Al/TiNi$_p$ Shape Memory Composites Fabricated by Powder Metallurgy”, *Journal of the Korean Institute of Metal and Materials*, Vol. 36, No. 3, 1998, pp. 469-477.
8. G.C.Lee, Y.C.Park, and Y.Furuya, “Recent Researches of Intelligent Structural Materials”, *Bulletin of the Korean Institute of Metals and Materials*, Vol. 7, No. 4, 1994, pp. 319-329.
9. I.M.Park, “Squeeze casting of Metal Matrix Composite”, *Proceedings of the 2nd Symposium on Solidification Process*, Seoul, Korea, August 21, 1991, pp. 86-91.
10. S.Miyazaki, S.Kurooka, A.Ishida and M. Nishida, “Effect of heat-treatment on deformation behavior associated with R-phase and martensitic transformations in Ti-Ni thin films”, *Advanced*

Materials ’93 V/B: Shape Memory Materials and Hydrides, edited by K. Otsuka and Y. Fukai, Vol. 18B, 1993, pp. 1041-1044.
11. P.G.McComick, Y.Liu, X.Chen and D.Favier “Multistage transformation behaviour in NiTi”, *Advanced Materials ’93 V/B: Shape Memory Materials and Hydrides,* edited by K. Otsuka and Y. Fukai, Vol. 18B, 1993, pp.1105-1108.
12. S.D.Wang, X.Z.Wu, J.P.Zhang, H.Q.Su, J.L.Jin and B.T.Song, “Phase transformation of rapidly solidified TiNi shape memor alloy”, *Advanced Materials ’93 V/B: Shape Memory Materials and Hydrides,* edited by K. Otsuka and Y. Fukai, Vol. 18B, 1993, pp.1061-1064.
13. H.C.Lin and S.K.Wu, “Effects of hot rolling on the martensitic transformation of an equiatomic Ti-Ni alloy”, *Material Science and Engineeering*, A158, 1992, pp.87-91.