# FABRICATION AND CHARACTERIZATION OF TiNi/$SiC_p$ SHAPE MEMORY COMPOSITES

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**Abstract :** Nickel–Titanium alloy near the equi-atomic concentration is well known for its shape memory effect (SME), and also its unique mechanical and physical properties, such as good ductility at ambient temperature, good vibration damping properties, long fatigue life and corrosion properties in sea water. In the present study Ni and Ti elemental powders with purity of 99.5% were used as starting materials. Production of NiTi/SiCp alloy from elemental powders was conducted by powder metallurgy (PM). The mixtures were compacted under a uniaxial pressure of 350MPa for 1 min. The cylindrical samples sintered in an argon-protected atmosphere for 3 h at 1150°C. The effects of SiCp additions, micro hardness, and porosity and corrosion behaviour on the characteristic of NiTi composites have been investigated. The samples were examined by scanning electron microscope (SEM), for microstructural studies and phase identification.

*Keywords:* NiTi Shape Memory Alloy, SiC, Powder Metallurgy, Corrosion.

## 1. INTRODUCTION

TiNi shape memory alloys (SMAs) have attracted significant interests due to their unique shape memory effect (SME), superelasticity and high damping performance [1−4]. These excellent physical and mechanical properties associated with the reversible martensitic transformation allow the commercial applications of TiNi SMAs in many fields, such as aerospace, biomedical and mechanical engineering [5, 6]. Generally, the most commonly used TiNi and TiNi-based alloys represent the major family of shape memory alloys [7]. On the other hand, continuous, short fiber, or particulate NiTi alloy reinforced metal matrix composites are attracting considerable interest due to their advanced mechanical properties. Usually, the shape recovery effect of NiTi reinforcements has been used to improve the mechanical properties of the composite materials. TiNi alloys have been fabricated using various methods like metal injection molding, hot izostatic pressing, combustion synthesis and spark plasma sintering. Solid state processes are generally used to obtain the best mechanical properties in titanium based composites. These processes exhibit excellent

finished performance due to the ability to obtain uniform distribution of reinforcement and near-net shape formability [8]. A significant contribution to NiTi fiber reinforced metal matrix composites have been made by Furuya et al. [9]. They reported improved tensile properties by creating compressive stress in the matrix caused by shape memory shrinkage of TiNi fibers. Later, Armstrong and Lorentz [10] and Armstrong et al. [11] reported that NiTi continuous fiber reinforced Al matrix composite combined high strength and high tensile toughness with unusual thermal mechanical behaviour. Dixit et al. [12] used friction-stir-process to prepare NiTi particle reinforced aluminium composite. They showed that improved mechanical properties could be achieved by using the shape memory effect of the NiTi particles to induce compressive and tensile stresses in the parent matrix. Porter et al. [13] investigated the fatigue and fracture behaviour of NiTi reinforced aluminium composite. They fabricated NiTi particle reinforced Al matrix composite using powder metallurgy and hot pressing and activated the shape memory effect by cold rolling. They reported significant improvement in the yield strength and ultimate strength compared with the monolithic Al samples, while the elongation was sharply reduced. A remarkable improvement on the fatigue life of the composite was observed particularly above the yield strength of the material. Xie et al. [14] and Xie et al. [15] developed short NiTi fiber reinforced Al6061 matrix composites prestraining the fibers at a temperature between martensite start temperature and austenite start temperature and investigated the relationship between the amount of prestrain and yield stress. They showed that the yield stress of the composite increase with increasing prestrain rates. However, a very limited study with reinforcement powders was used for manufacturing TiNi alloys. In recent study, the effects of SiC particle size on the microstructure and mechanical properties (hardness, porosity and corrosion) of pure Ti and TiNi/SiCp alloys with PM route have been investigated.

## 2. EXPERIMENTAL PROCEDURE

The test samples were prepared by powder metallurgy from Ni, Ti and SiC powders. Powders were produced by Alfa Aesar Company. In order to produce TiNi/SiCp based composites, Ti powders with an average particle size of 45 μm with 99.5% purity were chosen while SiC particles with 45 μm sizes were used as the reinforcements. The powders were weighed and put into a jar and then mixing was done with $T_2$-F turbula mixer. 1 wt. % and 5 wt. % SiCp were correspondingly mixed with TiNi powders. Then, the sufficiently blended powders were cold compacted into short-bar green samples (6 mm×10 mm, diameter × height) with a compact stress of 650 MPa for 1 min. The compacted green samples were

heated to 1100 °C and held for 3 h in an aluminium oxide tube furnace under the protective flowing argon gas (99.99% purity). Sintered specimens were cooled in the cold zone of the furnace at a rate of approximately 10-15 ◦C/min, sufficient to prevent formation of intermetallic other than TiNi due to possible oxidation problems that may occur during furnace cooling. Finally, all samples were produced using the same route. The theoretical-measured density, total porosity and water absorption were compared. The hardness of the composite and its alloy were measured by Vickers hardness (VHN) method and the mean of at least eight readings was taken. Corrosion tests were carried out in $H_2SO_4$ solution, pH-1.50 solution at RT and 45°C. Samples were placed in $H_2SO_4$ of pH-1.50 for 3 hours. The surface microstructures of the samples were examined using a scanning electron microscope (SEM, Model JEOL-JSM 6060-LV, Japan).

## 3. RESULTS AND DISCUSSION

### 3.1 DENSITY MEASUREMENT AND POROSITY

The theoretical densities of each composite specimen were calculated from powder mixes. The density of the composites was obtained by weighing small pieces cut from the composites disc first in air and water, and calculating the density by Archimedean method. The vacuum method (EN 14411) is used in the laboratory to determine water absorption, porosity, bulk density with greater precision. The composition of intermetallic composites, theoretical-measured density, total porosity and water absorption were compared (Table 1).

Table 1. The composition of intermetallic composites, theoretical-measured density, total porosity and water absorption.

| Material Types | Pure Ti | $Ti_{50}$+$Ni_{50}$ | Ti50+Ni49+1SiCp | $Ti_{50}$+$Ni_{45}$+5SiCp |
|---|---|---|---|---|
| Theoretical | 4,51 | 5,988 | 5,9175 | 5,6531 |
| Measured | 4,13 | 5,3 | 5,166 | 5,1375 |
| Total Porosity (%) | 2,05 | 4,068 | 5,03 | 6,12 |
| Water Absorption (%) | 0,99 | 0,373 | 1,95 | 5,62 |

### 3.2 HARDNESS TESTS

The variation of micro hardness of the composites is shown in Fig.1. This figure indicated that the hardness of the MMCs increased with increasing the content of particles up to 5wt. % and then decreased thereafter [16-17]. The hardness for pure Ti and its composite are about 404, 14 VHN, 459,42 VHN, 735,75 VHN and 756,4 VHN for the matrix, $Ti_{50}$+$Ni_{50}$ alloy, $Ti_{50}$+$Ni_{49}$+1SiCp composite, and $Ti_{50}$+$Ni_{45}$+5SiCp composites, respectively.

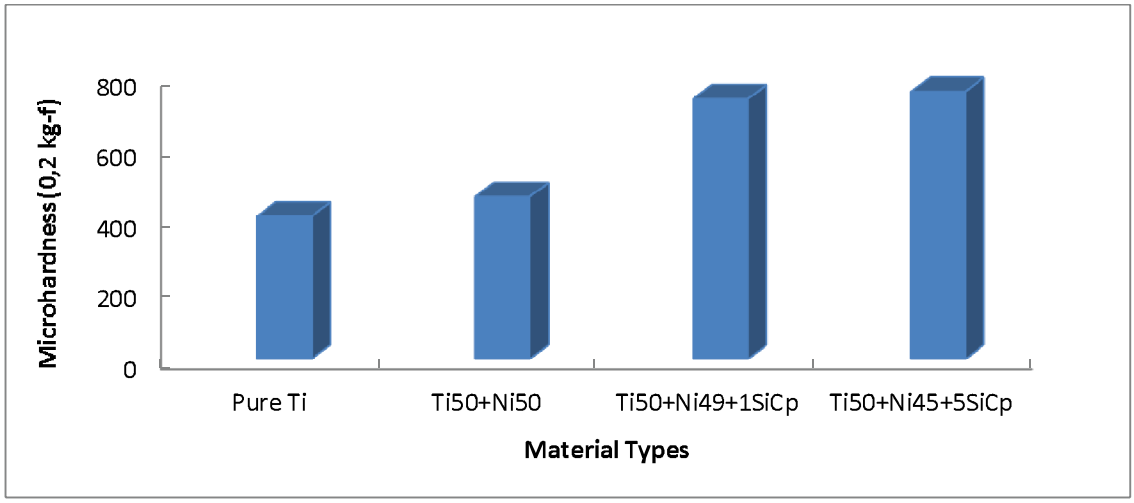
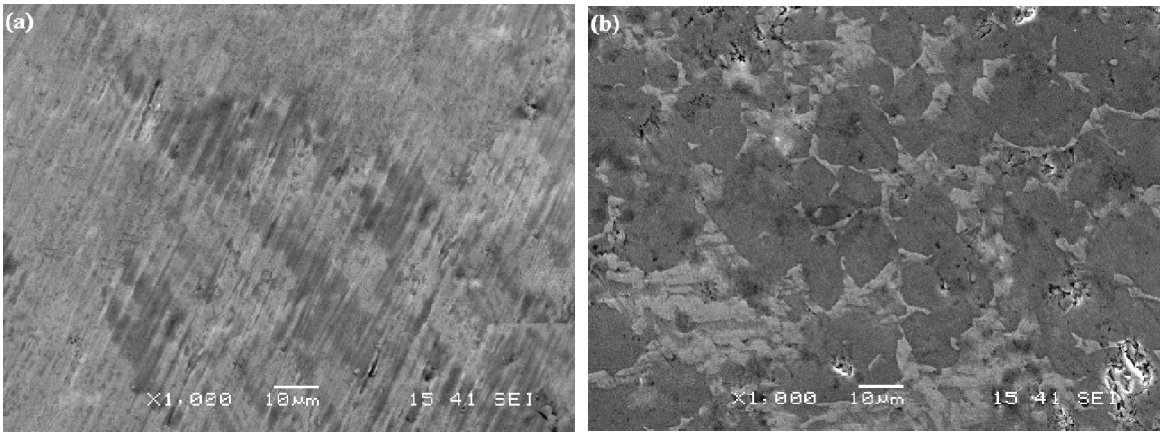



Fig.1. Micro hardness of TiNi alloy and it's composite.

### 3.3 MICROSTRUCTURE OF TiNi ALLOY AND ITS COMPOSITE

### SEM ANALYSIS

Microstructure of the composite was examined using SEM. After grinding and polishing, the composite samples were etched with solution of Kroll's Reagent. Fig. 2 is an SEM image of the pure titanium and it's composite after sintering 1150ºC 3h. The majority of the area shown was of the medium gray phase forming a matrix surrounding several smaller light gray and dark gray: black areas. The dark phase is rich in Ti and the bright in Ni, SiC particles are black. Each area was assumed to be a distinct phase or mixture of phases resulting from various stages of the progression of diffusion.



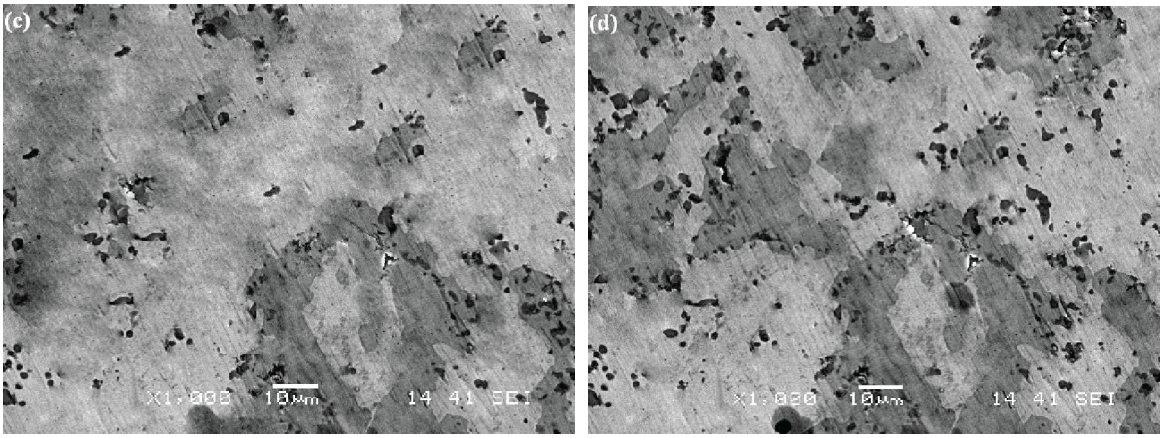



Figure 2. SEM images of the pure titanium and it's composite. (a) Pure titanium, (a) $Ti_{50}$+$Ni_{50}$ alloy. (c) $Ti_{50}$+$Ni_{49}$+1SiCp. (d) $Ti_{50}$+$Ni_{45}$+5SiCp.

Strong TiNi solid solutions presences were observed for the composite alloys (Fig.1b, c and d). It is attributed to the presence of content of Ni in these composite alloys. On the other hand, elemental dispersion of Ni and Ti is satisfactory, and SiC particles distributed into TiNi matrix, which confirms homogeneous structure formation (Fig. 2 c and d). At the beginning, it can be known that SiC particles are sharp-edged, having a particle size of ~40–45 μm. After sintering evaluation, the SiC particles were hanged on to the matrix and the surface of the composite specimens. Titanium nickel composite containing sub-micrometric SiC-particles and the dissolution of particle/metallic matrix composite in the interface between the titanium- nickel matrix and SiC particles. This microstructural features was responsible for the satisfactory values for the hardness and corrosion resistance for contents of SiC particles.

### 3.4 CORROSION TEST

Corrosion tests were carried out in $H_2SO_4$ with pH-1.50 solution at 3 hours. The test results are represented in Fig.3. It is clear from the result that pure Ti showed the best corrosion resistance, followed by silicon carbide reinforced based composites, but $Ti_{50}$+$Ni_{45}$+5SiCp alloy indicated the highest corrosion rate due to strongly regarding to the porosity level.

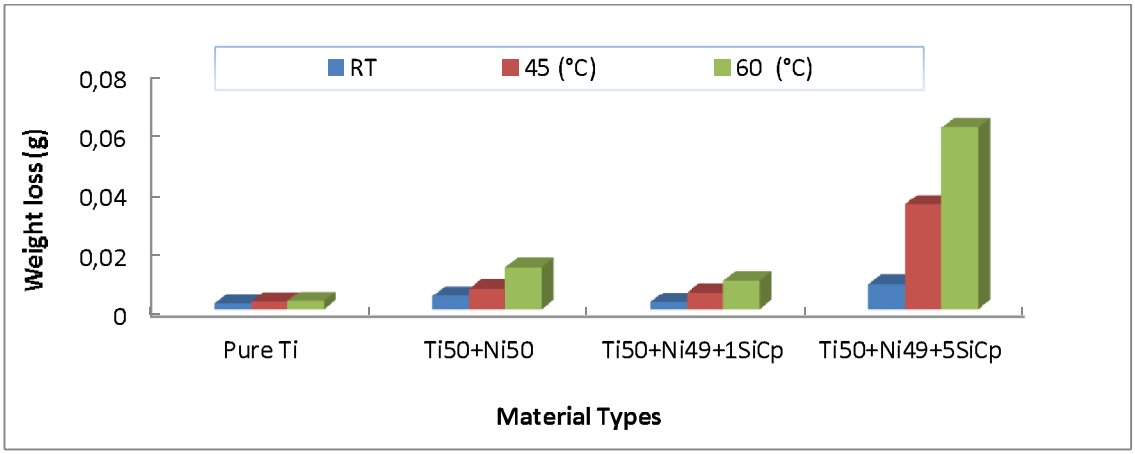



Figure 3. Corrosion test results on the composite samples.

## 4. CONCLUSIONS

In general, TiNi shape memory alloys were successfully fabricated by powder metallurgy process. The effect of SiC particles addition on microstructure and mechanical properties of TiNi alloy was investigated. In this exploratory work, the following results can be drawn:

• The fabrication procedure developed in this work did produce consolidated TiNi material with reasonably homogeneous microstructure.

• %5 SiC addition promoted an increase by 87.16% in hardness in the TiNi alloys;

• Among the tested samples, the best corrosion resistance was obtained for the Ti alloy because of lower porosity level.

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