# Characteristic Evaluation of Wear Properties of NiTiAl Based Shape Memory Alloys for different Composition

Babu K N[1], Mallikarjuna Biradar[2], Dr. N G S Udupa[3], Rudra Naik M[4], Santhosh N[5]
[1]PG Student (Machine Design), NCET Bangalore Affiliated to VTU, India.
[2]Associate Professor, Department of Mechanical Engineering, NCET, Bangalore, India.
[3]Prof. & Head, PG, Department of Mechanical Engineering, NCET, Bangalore, India.
[4]Assistant Professor, Department of Mechanical Engineering, NMIT, Bangalore, India.
[5]Assistant Professor, Department of Aeronautical Engineering, NMIT, Bangalore, India.
E-mail: babu.mech402@gmail.com

***Abstract*— Alloying constituents have a remarkable effect on the shape memory effect of Ni-Ti (Nitinol) based Shape memory alloys that have a rear distinction of having extremely effective characteristics as compared to other shape memory alloys. The transformational behavior of these shape memory alloys are unique and found to have an impact on biomedical applications. In our Present work the wear characteristics of Ni-Ti-Al based shape memory alloys were effectively studied for different compositions and the specific wear rate, hardness values were noted for as cast and heat treated samples. The results of the work has shown remarkable increase in hardness and wear characteristics of the shape memory alloys subjected to heat treatment and subsequent aging.**

**Keywords — Shape Memory Alloy, Wear, Hardness, Heat treatment, Nitinol.**

## 1. INTRODUCTION

Shape memory alloys are a unique class of materials that exhibit a phenomenon of transition between different physical domains that is, a shape-memory alloy (SMA) has an important characteristic of remembering its original shape which helps it to return to its pre-deformed shape even after undergoing deformation that may be either stress induced or pressure induced. Over a period of last decade, a number of alloys have been given the term shape memory alloys based on their outstanding transformational characteristics. Some of these alloys exhibit unique characteristics of variation in its shape and volume in response to the external stimulus such as temperature variation and variation in applied stress.

Since the last decade, TiNi shape memory alloy has attracted increasing interest from tribologists due to its high resistance to wear. The excellent performance of this alloy largely arises from its special deformation behaviour, the so-called pseudo elasticity, caused by a thermo elastic martensitic transformation [1–5]. The phase transformation involves a structural change from the parent phase 32($\beta$), to a martensitic phase (monoclinic) [6]. Prior to the martensitic transformation, another phase transformation may also occur, depending on the composition of the alloy and heat treatment. This transformation involves a structural change from the Body centred (B2) phase to a rhombohedral phase (R phase) [7–9].

These two transformations are reversible and can be induced either by changing temperature or by applying stress [10–16]. The high wear resistance of TiNi alloy has been well demonstrated [18–31]. A number of researchers have investigated the wear behaviour of TiNi alloy in different wear conditions and compared it to conventional engineering materials such as steels, Ni-based and Co-based tribo-alloys [20, 23–25, 27, 30, 31, 45]. It is observed that TiNi alloy performs better than these conventional wear-resistant materials.

In addition, TiNi alloy also exhibits high resistance to corrosion [29, 32] and this makes TiNi alloy attractive for application in “wet” or corrosive environments, such as cavitations and liquid impact
[29, 33].

The contribution of pseudo elasticity to the wear resistance has been directly and indirectly confirmed. Shida and Sugimoto [21] observed remarkable erosion resistance of TiNi alloy during a water-jet erosion test. They found that the optimal composition that corresponded to the minimum erosion was in the range from Ti–55 wt. % Ni to Ti–56.5 wt. % Ni, where the TiNi alloy behaves pseudo elastically. Liang et al. [27] observed that the specimens with pseudo elasticity had higher wear resistance than those with little pseudo elasticity.

Attempts have been made to apply TiNi alloy as a tribo material with success in chemical plants and power stations as reported [20, 29]. Since TiNi alloy is relatively expensive, considerable efforts have been made to develop TiNi coatings using various processes, such as sputtering [35, 36], plasma spray [37], explosive welding [24] and plasma ion plating [38]. The success in making TiNi coatings has made the industrial application of TiNi alloy feasible.

## 2. METHODOLOGY ADOPTED

1. Preparation of Nickel, Titanium and Aluminium in the form of tiny particulates and chips for further processing.
2. Weighing of Nickel, Titanium and Aluminium in suitable proportions as per the requirements.
3. Melting of Nickel, Titanium and Aluminium weighed for suitable proportions in Vacuum arc remelting furnace.
4. Drawing the buttons of Ni-Ti-Al melted in vacuum arc remelting furnace in Vacuum suction casting setup to obtain rods of 60 mm length and 6 mm diameter.

5. Abrasive wear of the both as cast and heat treated samples as per ASTM Standards on AA60 alumina (60μ) grinding wheel from M/s carborundum.
6. Hardness testing of the samples as per ASTM Standards from Vickers hardness tester configured and calibrated.
7. Tabulation of the results and Drawing of suitable conclusions in correlation with the data obtained.

## 3. COMPOSITION OF THE ALLOY

Table 1 shows the composition of the different elements selected as per earlier literature review carried out in detail.

| | Ti | Ni | Al | Total |
|---|---|---|---|---|
| Alloy | At % | At % | At % | Total (%) |
| NiTi | 50 | 50 | 0 | 100 |
| NiTiAl | 50 | 47 | 3 | 100 |
| NiTiAl | 50 | 44 | 6 | 100 |
| NiTiAl | 50 | 41 | 9 | 100 |

Table – 1: Composition of different elements

To weigh out the materials, conversions from atomic percentage at (%) to weight percentage wt (%) are done by using the following relation.

$$\text{Wt \%A} = \frac{(Atomic\%A * AtomicWtA)}{(Atomic\%A * AtomicWtA) + (Atomic\%B * AtomicWtB) + (Atomic\%C * AtomicWtC)}$$

Table – 2 gives atomic weight for different elements.

| **Element** | **Atomic Weight** |
|---|---|
| **Ti** | 47.88 |
| **Ni** | 58.69 |
| **Al** | 26.98 |

Table – 2 Atomic Weight of different elements

## 4. ABRASIVE WEAR TEST

Abrasive wear for the three compositions was carried out for both the as-cast and heat-treated samples for different load conditions and track diameter using pin-on-disc apparatus fitted with an AA60 alumina (60μ) grinding wheel from M/s carborundum. The Speed, time and load for which wear test is done is tabulated as shown in table – 3.

| | Load(kg) | Speed(rpm) | Time(sec) | Wear (microns) |
|---|---|---|---|---|
| NiTiAl as-cast | 1 | 300 | 600 | 27 |
| | 2 | 300 | 600 | 52 |
| NiTiAl HT300 | 1 | 300 | 600 | 57 |
| | 2 | 300 | 600 | 83 |
| NiTiAl HT 350 | 1 | 300 | 600 | 68 |
| | 2 | 300 | 600 | 121 |
| NiTiAl HT 400 | 1 | 300 | 600 | 94 |
| | 2 | 300 | 600 | 152 |

Table – 3 Speed , Wear and Load conditions

## 5. VICKERS HARDNESS TEST

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136º between opposite faces subjected to a load of 5 kg. This load is reasonably big and should give an acceptable hardness for a cast metal. The 3mm diameter castings could not be tested by Brinell. Further the high hardness also precludes the use of Brinell which is the suggested method for cast materials. The full load is normally applied for 10 to 15 seconds. The two diagonals of the square indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kg load by the area of indentation (in square mm).

The Vickers Diamond Pyramid harness number is the applied load (kg) divided by the surface area of the indentation ($mm^2$)

Fig 1 shows the Vickers hardness tester used for finding the Vickers hardness number of the given specimens.

Fig 1 Vickers hardness tester

## 6. FORMULAE USED FOR DATA ANALYSIS

Formulae used in determining specific wear rate

1) Sliding distance(S) = $\pi DNT/1000$ (m)

Where D = Diameter of Disc (mm)
N = Speed in rpm
T = Time in minutes

2) Sliding speed (V) = $\pi DNT/ (1000\times 60)$ (m/s)

3) Specific Wear Rate (SWR) = $\Delta V/ (L\times S)$ *(mm3/N-m)*

Where $\Delta V$ =Volume loss ($mm^3$) = $\Delta LXA$
Where $\Delta L$= Loss in length (mm), A = Area of specimen ($mm^2$)
Where D = diameter of the specimen, L= Load (N), S=Sliding distance (m)

4) Hardness (HV) = $(2F\sin 136/2)/d^2$,
HV = $1.854\ F/d^2$

Where: F= Load in kg
d = Arithmetic mean of the two diagonals, d1 and d2 in mm
HV = Vickers hardness in $kg/mm^2$

## 7. RESULTS

### 7.1 HARDNESS

The hardness results of the compositions in both as-cast and heat-treated condition is shown in the table below.

From the table it can be seen that the hardness values tend to go up with an increase in the heat- treatment temperature. As the alloys are heat-treated at low aging temperatures of 300 and 350°C, the hardness is seen to go up possibly due to the formation of transition precipitates and still when the samples are heat-treated to higher temperatures like 400°C, the hardness further increases due to the formation of equilibrium precipitates.

It is observed from each of the hardness values that addition of Al to NiTi matrix has brought about a sufficient amount of solid solution hardening.

| Aging Temperatures | Load (in kg) | NiTiAl (VHN) |
|---|---|---|
| As-Cast | 05 | 401 |
| 300°C | 05 | 469 |
| 350°C | 05 | 490 |
| 400°C | 05 | 503 |

Table – 7 Hardness value for different aging temperatures

### 7.2 ABRASIVE WEAR

| Specimen | Load(kg) | Speed(rpm) | Time(sec) | NiTiAl |
|---|---|---|---|---|
| **As-Cast** | 1 | 400 | 600 | 155 |
| **300°C** | 1 | 400 | 600 | 141 |
| **350°C** | 1 | 400 | 600 | 132 |
| **400°C** | 1 | 400 | 600 | 108 |

Table – 5 Abrasive wear of 1 kg load

It is clearly observed from the above table that wear is exactly the inverse of hardness. As the hardness of a sample goes up, the wear is seen to come down.

It is seen from the wear results of NiTiAl composition that the wear of the as-cast NiTiAl sample is the maximum which gradually reduces upon increasing the heat-treatment temperature upto 350°C. Wear reduces drastically in samples heat-treated at 400°C. The sudden decrease of the wear in samples heat-treated at 400°C may be due to the formation of equilibrium precipitates from the transition precipitates.

Similarly, in other compositions where Aluminium is added in terms of 6% and 9%, the trend of wear for the samples remains similar to NiTiAl(3%) composition but in general, the wear of all the other samples having 6% and 9% aluminium respectively is usually less as compared to NiTiAl(3%) samples because of additional hardening effect of Aluminium.

| **Abrasive Wear in Microns** | | | | | |
|---|---|---|---|---|---|
| | **Load (Kg)** | **Speed (rpm)** | **Time (sec)** | **NiTi** | **NiTiAl (3%)** |
| **As-Cast** | 2 | 400 | 600 | 340 | 271 |
| **300°C** | 2 | 400 | 600 | 325 | 258 |
| **350°C** | 2 | 400 | 600 | 298 | 231 |
| **400°C** | 2 | 400 | 600 | 277 | 198 |

Table – 6 Abrasive wear results of 2 kg load

It is clearly seen that the trend of wear distribution for 2 kg load is similar to the trend of wear distribution for samples subjected to 1 Kg load. But the wear of the samples that has taken place at 2 kg load is almost twice that of 1 kg load.

Also the specific wear rates are calculated from the wear data for the specimens of both the compositions for the as-cast and heat-treated conditions subjected to 1 and 2 kg load.

It is also seen from the table that the abrasive wear reduces drastically with heat treatment up to 400°C mainly due to the formation of transition precipitates in the inter metallic bonds of Ni-Ti that is essentially due to age hardening.

## 8. CONCLUSION

1. The Vickers hardness is low for the as-cast samples but gradually increases with increase in the heat-treatment temperatures up to 400°C possibly due to transition precipitates.
2. The Vickers hardness number varies from a minimum of 401 VHN for as cast specimens to a maximum of 503 VHN for samples subjected to heat treatment at 400°C.
3. Abrasive wear show a trend that is exactly the inverse of Vickers hardness. The wear rates tend to decrease from as-cast condition up to 400°C heat-treated condition, and it varies from a maximum of 271 microns to a minimum of 198 microns.

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