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ANALYSIS OF TRIBOLOGICAL PROPERTIES OF TI-NI-CU SHAPE MEMORY ALLOY

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Abstract - There are a number of alloys, which exhibit the shape memory effect; however, not all of them generate large strains or forces when activated. Two SMAs which generate large amounts of strain and are capable of generating a large force upon transformation back to the austenitic phase are nickel titanium (Ni-Ti) alloys and copper (Cu) based alloys such as Ti-Ni-Cu can recover up to 6% strain. TiNi alloys tend to be more thermally stable, ductile and corrosion resistant than the Cu based alloys. However the Cu based alloys are less expensive to produce and are easily melted and extruded in air with a larger range of transformation temperatures available. A comparison of the properties of TiNi, CuZnAl and CuAlNi can be found. Experiments have been conducted by varying the percentage of copper combination in Ni-Ti alloy, to find out the variation of hardness and the wear properties. It is understood with the increase of copper percentage; hardness has been increased resulted in the wear resistance characteristics.

I. INTRODUCTION

Wear is a common problem in different applications. Recently the number of application of TiNiCu is increasing. However, little work has been reported on wear behavior of TiNi and its alloys. Ti-Ni-Cu ternary SMAs are found to be the most promising alloy system for actuator applications where large number of cycling is involved. The TiNiCu alloy is being actively applied to the development of new energy conversion system, to the design for new robots and smart material system, and to the development of medical implants and instrument [6]. The shape memory effect is a unique property of certain alloys exhibiting martensitic transformation the alloy is deformed in the low temperature phase, it recovers its original shape by the reverse transformation upon heating to a critical temperature called the reverse transformation temperature. This effect was first found in a Au-47.5at% Cd alloy by Chang and read in 1951[1] and then it was discovered in TI-Ni alloys by Burkart in 1953[1]. Actual applications were realized after the shape memory effect was found in a Ti-Ni alloy by Buehler in 1963[1]. Cu-Al-Ni alloy was also found to reveal the shape memory effect by Arbuzova in 1964[1]. But Cu based alloys are brittle in polycrystalline state. The basic understanding of the shape memory mechanism and crystallography of the martensitic transformations has been obtained for the Ti-Ni alloys by Miyazaki in 1966[1]. The same alloys have another unique property called 'superelasticity' at a higher temperature , which is associated with a large nonlinear recoverable strain up on loading and unloading .Since these alloys have a unique property automobile applications, antennae for cellular phones and medical implants and guide wires etc[2].

1.1 *TiNi and Cu Based Alloys*

There are a number of alloys, which exhibit the shape memory effect; however, not all of them generate large strains or forces when activated. Two SMAs which generate large amounts of strain and are capable of generating a large force upon transformation back to the austenitic phase are nickel titanium (Ni-Ti) alloys and copper (Cu) based alloys such as Ti-Ni-Cu can recover up to 6% strain. TiNi alloys tend to be more thermally stable, ductile and corrosion resistant than the Cu based alloys. However the Cu based alloys are less expensive to produce and are easily melted and extruded in air with a larger range of transformation temperatures available. A comparison of the properties of TiNi, CuZnAl and CuAlNi can be found. The physical properties of the alloys depend largely on their composition. For example, Ni-Ti alloys are most effective when they have a binary, equiatomic composition [6 and 10].

II. EXPERIMENTAL ANALYSIS

Three sample specimens of TiNi with varying copper weight percentage are prepared to study the various mechanical properties like hardness, wear studies and microstructural analysis shown below the Table 1.

Specimens	Ti(wt%)	Ni(wt%)	Cu(wt%)
Sample -1	4.45	4.83	0.71
Sample-2	4.46	4.61	0.92
Sample-3	4.34	4.49	1.16

in remembering the original shape, having an actuator function and having superelasticity, they are now being used for various applications such as pipe coupling, various actuators in electric appliances,

Table1. Percentage variation of Cu in samples

2.1 Microstructural Analysis

Microstructural analysis of samples was done for both before and after the wear test. The cylindrical pin sample was initially polished using different grades (200 and 300 grits) of emery papers. Further polishing was done on disc polish using velvet cloth and colloidal alumina. Final polishing was done on disc cloth and diamond paste having particle size 3µm, 1µm, 1/4µm respectively.

2.2 Scanning Electron Microscopy

The micro structural analyses were carried out using Scanning Electron microscope (SEM). The SEM used was JEOL make JSM 6380 LA model. Scanning electron analyzer was used to study the wear surface before and after the pin-on-disc wear tests. Back scattered electron mode was used to obtain the worn surface images. Care was taken not to disturb the wear surfaces and was cleaned with acetone and dried in air before taking the images. The JSM-6380 specimen chamber can accommodate a specimen of up to 6-inches in diameter. Standard automated features include auto focus, auto gun and automatic contrast and brightness

2.3 Wear Test

The pin-on-disc machine was selected for this work. Wear test conducted using pin-on-disc wear test machine (TR-201CL PIN-ON-DISC MACHINE).

The machine has facilities to monitor wear and friction under dry and lubrication condition. Sliding occurs between the stationary pin and a rotating disc. Normal load, rotational speed and wear track diameter can be varied to suit the test conditions.The wear test has been carried out on TiNICu alloy with specimen of 4 mm diameter and 1 cm length were prepared with above alloy and wear test were carried out under normal load (one, two and three kg) and track diameter of 80 mm, with constant speed at 250 rpm. Before starting the experiment, pin was abraded against a fine abrasive paper of grade 1200 (grit size 5 µm) for uniform contact and the pin was cleaned with acetone. A brush was used to remove foreign particles followed by weighing on a precisa XB120A balance with an accuracy of 0.0001g.

2.4 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 1 to 100 kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the 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.

III. RESULTS AND DISCUSSION

The effect of different percentage of copper on dry sliding wear has been reported for TiNiCu alloy. The investigation was carried out with the aim of identifying crucial factors that can improve the tribological properties of TiNiCu alloy

Load (kg)	Speed (rpm)	Time (sec)	Weight loss (g)	Sp. Wear Rate (mm^3/N-m)X 10^{-5}
1	250	600	0.019	4.629
2	250	600	0.023	2.873
3	250	600	0.028	2.296

Table 2.1 Wear test at 0.7 percentage of Cu with constant load and time

Load (kg)	Speed (rpm)	Time (sec)	Weight loss (g)	Sp. Wear Rate (mm^3/N-m)X 10^{-5}
1	250	600	0.017	4.267
2	250	600	0.020	2.492
3	250	600	0.025	2.014

Table 2.2 Wear test at 0.9 percentage of Cu with constant load and time

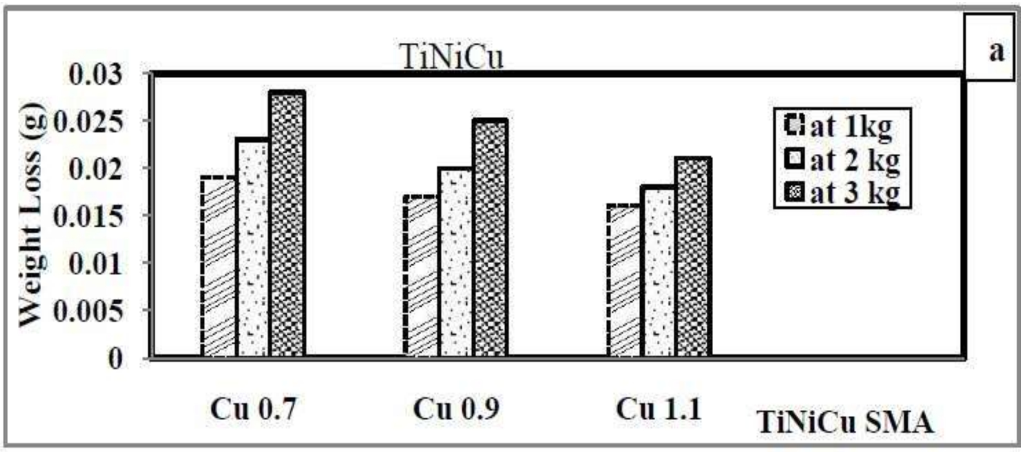
Load (kg)	Speed (rpm)	Time (sec)	Weight loss (g)	Sp. Wear Rate (mm^3/N-m)X 10^{-5}
1	250	600	0.016	3.976
2	250	600	0.018	2.246
3	250	600	0.021	1.926

Table 2.3 Wear test at 1.1 percentage of Cu with constant load and time

Table 2.1,2.2,2.3 shows the effect of percentage of copper of TiNiCu alloy under different load, constant sliding speed and constant sliding distance. The present results suggest that, the weight loss is increases with increasing load but wear load is decreasing with increasing the copper content to the TiNi SMAs. As expected from its higher hardness. The TiNiCu SMAs alloys of wear resistance decreases with increasing the copper content in the alloys due to the hardness.

3.1 Comparison Graphs:

Comparison graphs have been drawn for varying composition of copper in TiNi SMA at different loads have been plotted



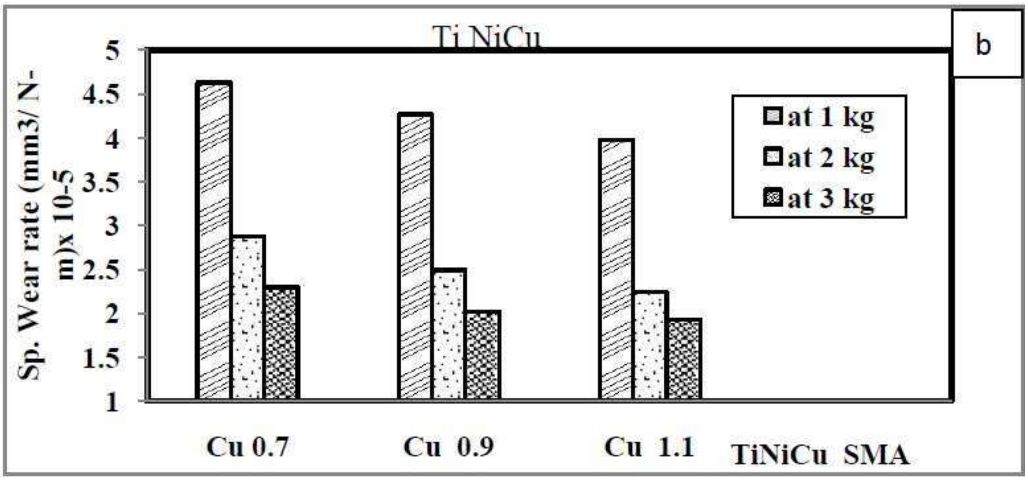


Figure 1. Comparison graphs of (a) Weight loss and (b) Sp.wear rate with different percentage of Cu

3.2 Optical Microstructure Of TiNi SMAs Before Wear

Optical micrographs have been taken for various combination of Cu in TiNi SMA .The microstructure of the ternary TiNiCu alloys with different percentage of copper Fig 4.4 (a, b and c) reveals the existence of the austenitic (β phase) microstructure. Microstructure consists of both α (white) and β (black) - phase, close examination of microstructure reveals that volume fraction of α –phase is very much higher than volume fraction of β – phase is increasing as the increasing the copper content. Majority of the area reveals the presence of fine and euqiaxed grains with more are less uniform size and along with few large sized grains.

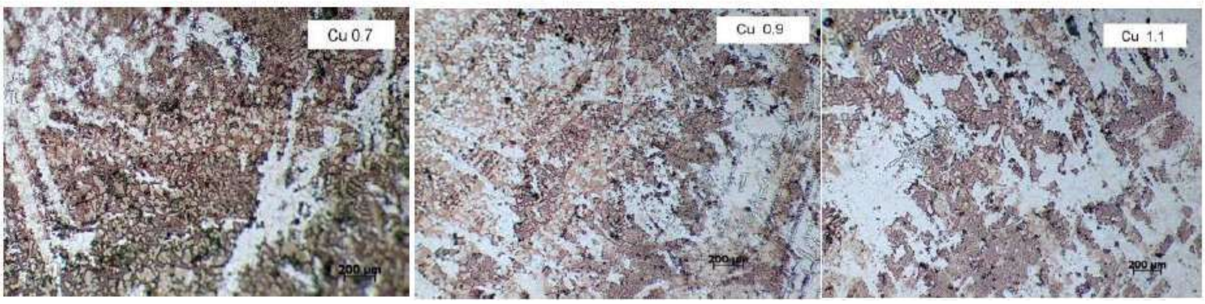


Figure 2.Optical microstructure of different percentage of Cu

3.3 Scanning Electron Microscope

The microstructural observation using SEM were also carried out before the wear test for the specimens of TiNiCu SMAs alloys. Fig 4.5(a, b and c) shows the microstructure of the specimens have the grains are elongated and fine grain boundary regions which are continuous. Moreover within the grains ultrafine white precipitates can be observed. Dark regions were present within the microstructure. Lamellar structure can be clearly seen in the micrograph of all the specimens. Microstructures of TiNi SMA with various combinations of Cu have been observed as shown below

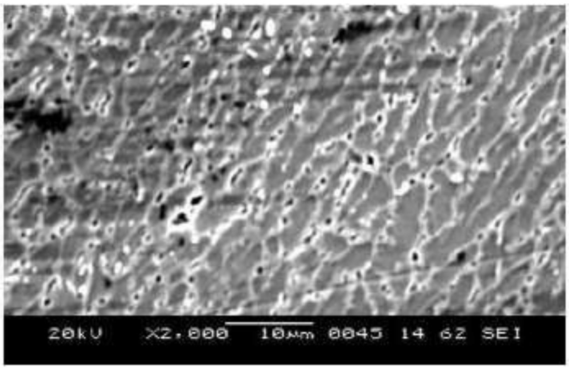


Figure 3. Percentage of cu at 0.7

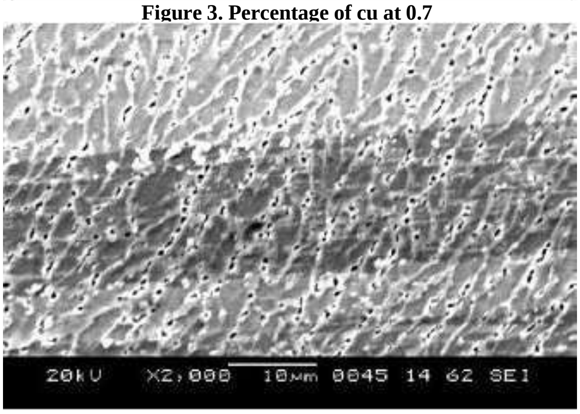


Figure 4. Percentage of cu at 0.9

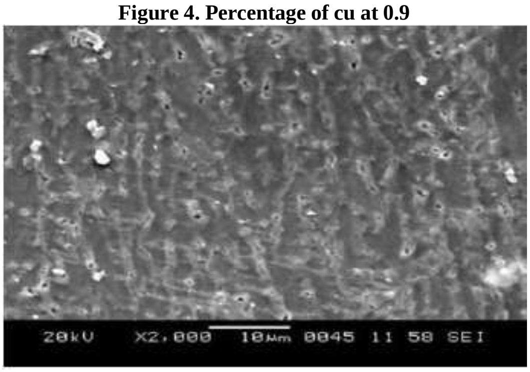


Figure 5.Percentage of cu at 1.1

3.4 Hardness

Hardness is one of the important material properties, which strongly influences the wear behavior. When the wear mechanism of TiNiCu alloy is discussed, the hardness is addressed as very important property. Fig 4.13 (a, b and c) shows the variation in hardness with percentage of copper. The microhardness is increased with the increasing the copper content to the TiNiCu SMAs alloys

Specimen	Load(Gm)	Vickers Hardness Number(HV)
Cu 0.7	500	534
Cu 0.9	500	573
Cu 1.1	500	613

Table 3. Effect of hardness of TiNiCu alloy.

3.5 Effect Of Cu Content

In the present work, wear rate was measured for different percentage of copper (Cu) to the TiNi Shape memory alloys. The wear resistance of the materials undergoing wear by the interaction of asperities predicted by Archard's equation. Archard's contact model analyses the interaction between asperities which undergo elastic-plastic deformation and fatigue failure. According to Archard's equation harder material have higher wear resistance [7]. From Figure 1(a) and (b) the weight loss is increases with increasing load but wear loss is decreasing with increasing the copper content to the TiNi SMAs and specific wear rate also decreasing at different loads due to the hardness.

IV. CONCLUSION

The sample specimens were successfully prepared by varying the percentage of Cu in TiNi SMA. The following properties were observed during the experimental procedure The metallurgical properties, wear load, sliding distance, and sliding speed all have considerable influence on the wear characteristics of TiNiCu SMAs alloys. The TiNiCu alloy exhibits better wear resistance due to higher hardness and pseudoelastic behaviors. The wear rate decreased with increasing the percentage of copper in to the alloy at different loads due to increasing hardness. The weight loss occurs with increasing the load due to plastic deformation. Four main mechanisms, adhesion, abrasion, surfaces fatigue and brinelling are found to have important contribution to the wear characteristics. Wear occurs by plastic deformation and cracking of matrix followed by delamination. Hardness of TiNiCu SMAs alloy is increased due to copper content increasing to the alloys.

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