Actuation Characteristics of 0.15mm Diameter Flexinol® and Biometal® Wire Actuators for Robotic Applications

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ABSTRACT

In this paper the actuation properties of two NiTi (Nickel Titanium) SMA (Shape Memory Alloy) actuators available under the commercial names of Flexinol® and Biometal® are investigated and compared with each other. Both actuators have diameter of 0.15mm and transformation temperature of 70°C. The diameter of 0.15mm is selected because of best combination of force and cooling time. An experimental test rig specially designed and developed by the first author was used to conduct tests on the actuators. Both actuators were tested by supplying actuation voltages of 5 and 5.5V. Actuators were thermomechanically loaded for 100 cycles and their strains were recorded. The results of the tests show that 5.5V actuation resulted in greater strain. It was found from the test results that Biometal® actuators produced more strain as compared to Flexinol® actuators for both the actuation voltages. However, the drift results showed that higher strains in Biometal® are due the permanent deformation of the same. This shows that Flexinol® actuators possess better actuation characteristics as compared to Biometal® actuators.

Key Words: **Flexinol®, Biometal®, Electric Actuation, SMA Characterisation.**

1. INTRODUCTION

SMAs belong to the group of materials that undergo change in the microstructure when subjected to change in temperature and/or stress [1]. This transformation is very useful as it is accompanied by release of energy. This energy, then, can be used to actuate any mechanical component. Shape memory alloys possess very high strength-to-weight ratio, their operation is noiseless and they undergo muscle like movement. These attributes make SMAs a very suitable candidate for prosthetic [2], robotic [3] and MIS (Minimally Invasive Surgery) applications [4].

In current research, two commercially available NiTi SMAs are tested for actuation behaviour. The research presented in this paper was undertaken to select the best actuator to develop a bundled actuator for actuating a robotic finger [5]. It was important to fully investigate the actuation behaviour of the SMA actuators as their actuation behaviour is yet not fully understood. Moreover, the data sheets provided by the manufactures are not exhaustive. For instance, no exact strain data is provided by both the manufactures; only a wide range of 3-5% strain is mentioned. The first original contribution of authors

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presented in this research is the design and development of the test rig that uses load cell, thermocouple and displacement laser sensor. The second original contribution is the comparison of actuation properties of the two commercially available actuators.

2. SHAPE MEMORY ALLOY ACTUATORS

SMAs exhibit SME (Shape Memory Effect) which helps them to get back to their original shape (microstructure) when deformed and/or heated. There are quite a number of alloys that exhibit this behaviour. They include, but are not limited to, Cu-Al-Ni (Copper-Aluminium-Nickel), Ni-Al (Nickel-Aluminium), Ni-Ti (Nickel-Titanium), Mn-Cu (Manganese-Copper) and Fe-Mn-Si (Iron-Manganese-Silicon) [6]. Due to better ductility, higher strains, better anti-corrosion, biocompatibility and electrical heating option, Ni-Ti based alloys have found wide spread use [7]. The SME in SMA actuators is due to two temperature dependent phases (Fig. 1); one is a high temperature (70^{o}C and above for actuators used in this research) phase known as Austenite and the other is low temperature (less than 70^{o}C) phase known as Martensite. As SMAs are softer in the Martensitic state [8], they can be easily deformed. Heating above transformation temperature results n phase change from Martensite to Austenite. This phase change is accompanied by actuator strain which can develop large stresses of the magnitude of up to $6x10^5$ Pascal. The strains of up to 8% are possible, but for cyclic applications strains must be confined to 5% [9].

3. MATERIALS AND METHOD

3.1 Purpose-Built Test Rig

An experimental setup (Fig. 2) was designed and developed by first author to carry out experiments on 0.15mm diameter actuators. Force, laser displacement and temperature sensors were used to measure bias force strain and temperature of the wire actuator respectively. The design and development of the instrumented test rig using laser displacement sensor is the original contribution. Fig. 2 shows experimental setup to carry out tests on wire actuators. A linear servo amplifier was used to actuate the actuators. LabVIEW® 2010 software and National Instruments data acquisition card were used for data acquisition. Mosley and Mavroidis [10,11] have also developed a test rig to characterise the SMA bundled actuators but that test rig has two shortcomings. One, it uses LVDT (Linear Variable Differential Transducer) to measure length of stroke (strain) of the actuator. LVDT is a contact sensor so it interferes with the measurements. Two, load cell to measure tension in the actuator is placed at the bottom end of the actuator hence weight of the load cell is added to the bias force being applied to actuator. This also interferes with the measurements. In this paper the test rig designed and developed uses laser displacement sensor instead of LVDT and load cell is mounted on the top end of the actuator. Hence, sensors used in the test rig do not interfere with the measurements. This results in accurate measurements.

3.2 Actuators

Literature review was carried out to identify two leading manufacturers (Dynalloy® Inc. US and of Toki® Corp., Japan) of the Ni-Ti based SMA actuators. Both Flexinol® (product Dynalloy® Inc. US) and and Biometal® (product

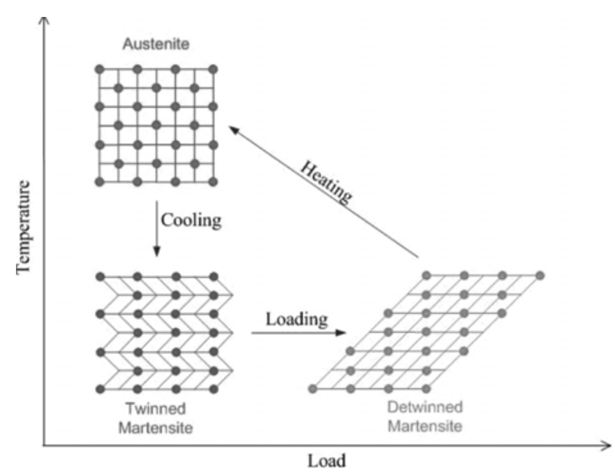

FIG. 1. THERMOMECHANICAL TRANSFORMATION IN SHAPE MEMORY ALLOYS [10]

of Toki® Corp., Japan) actuators are available in various diameters. As both pull force and cooling time (and hence cycle time) of the actuator are functions of the diameter of the actuator, a plot (Fig. 3) of Pull force and Cooling time vs. Diameter of the actuator was produced from the data sheet of supplied by the manufacturer (Dynalloy, Inc, US). This plot shows that the diameter of the actuator is directly proportional to the amount of force developed and the time required to cool off. In this research, 0.15mm (150μm) diameter wire actuators were selected due to two reasons listed as:

(i) The data sheet for the Flexinol® 150 LT actuator [9] provides that for diameters up to 0.15mm the electric current that causes the actuation in 1s shall not overheat the actuator.

(ii) The cooling times for the wires having diameters larger than 0.15mm are relatively large. For instance, the cooling time for the actuator having diameter of 0.15mm is 1.7s, the cooling time for the same type of actuator having a diameter of 0.2mm is 2.7s and the cooling time for the actuator having the diameter of 0.25mm is 4.5s [8].

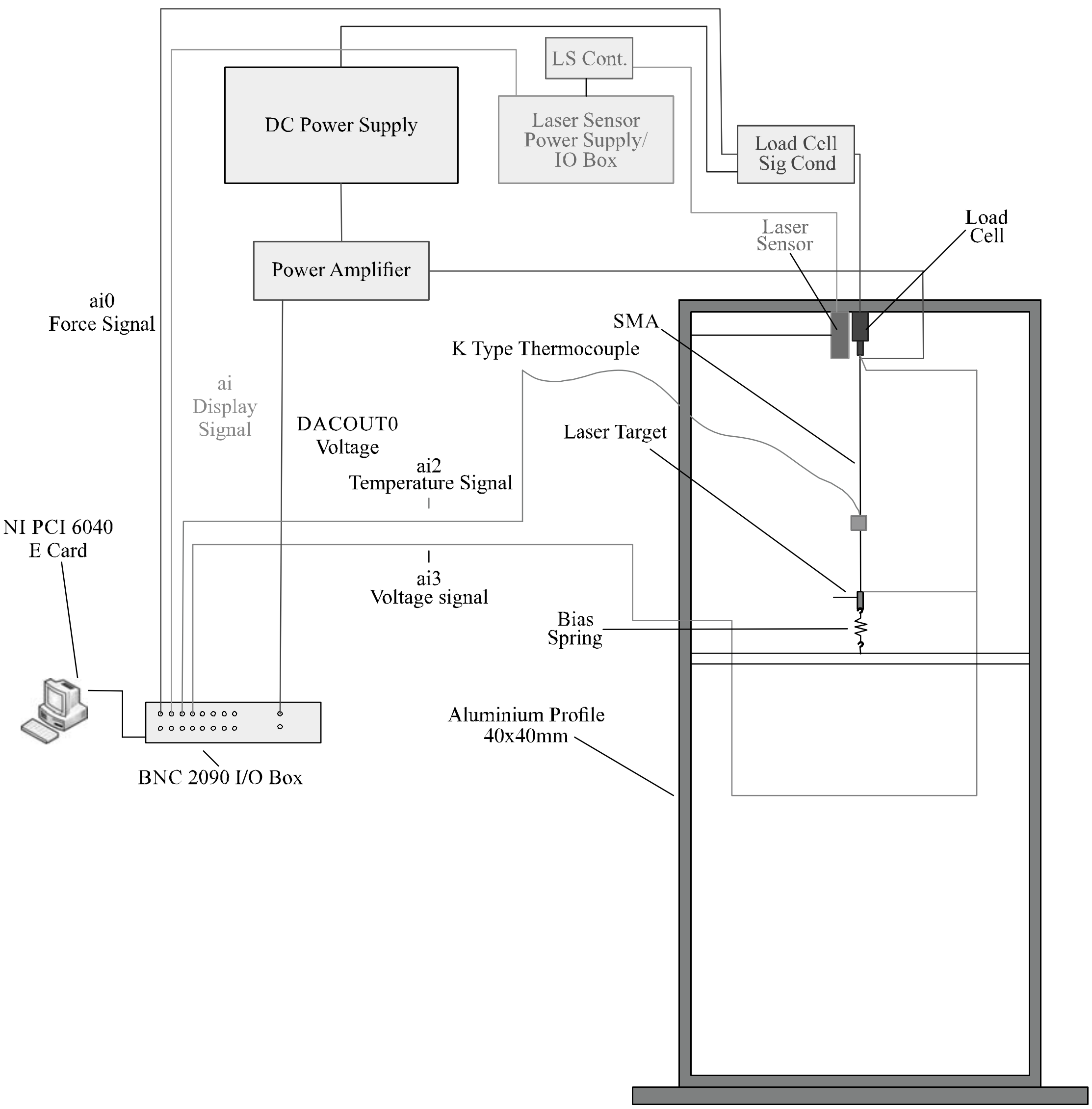

FIG. 2. INSTRUMENTED TEST RIG TO CHARACTERISE SINGLE WIRE SMA ACTUATORS

The properties of the 0.15mm diameter wire actuators used in this research are given in Tables 1-2.

3.3 Statistical Tests on the Diameters of the Actuators

The diameters of a 5m long actuators of each Flexinol® 150 LT and Biometal® 150 were measured twenty times by using a digital micrometer. The descriptive statistics of the measurements is given in Table 3. The statistics showed that both actuators were produced at high accuracy and precision as standard deviation is very small.

4. TEST RESULTS AND DISCUSSION

4.1 Test Parameters

An extension spring was used to apply bias force to the actuators. The Initial tension applied to actuators was set to 2N as per recommendation of the manufacturer of the Flexinol® 150 LT actuators. This corresponded to 113 MPa for diameter of 0.15mm. A cooling off period of 8 s was allowed to the actuators so that actuators were completely cooled down to Martensitic phase before they were heated for the next cycle of operation. Test rig was placed inside the enclosure to isolate actuators from the ambient air currents and to maintain a constant ambient temperature. The summary of the test parameters is given in Table 4.

Each actuator was cycled for 100 times. Each cycle was of 10s duration, comprising of 2s for heating and rest of 8s for cooling. Strain of Flexinol® 150 LT and Biometal® actuators is plotted in Figs. 4-5 respectively. Fig. 4 shows a plot of strain against the number of cycles for Flexinol® 150 LT. A 5.5V input produces larger strains than that of 5V. This was because of the fact that more Martensite was

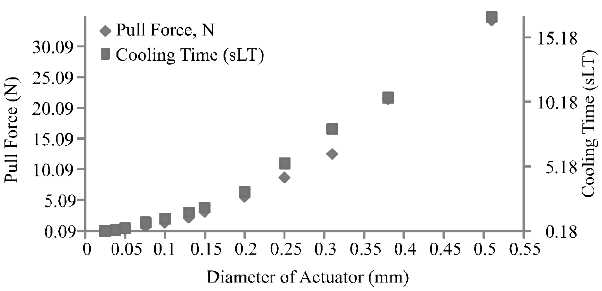

FIG. 3. DIAMETER, PULL FORCE AND COOLING TIME RELATIONSHIP FOR LEXINOL® 150 LT

TABLE 1. PROPERTIES OF BIOMETAL® (PRODUCT OF TOKI® CORP)

Diameter, mm	0.15
Practical Force Produced, N	1.47
Practical Kinetic Strain, %	4
Service Life, times	$\sim 10^6$
Standard Drive Current, mA	340
Standard Drive Voltage, V/m	20.7
Standard Power, W/m	7.05
Linear Resistance, Ω/m	61
Tensile Strength, N	17.65
Weight, mN/m	1.1

TABLE 2. PROPERTIES OF FLEXINOL® 150 LT (PRODCUT OF DYNALLOY® CORP. USA)

Diameter, mm	0.15	
Practical Force Produced, N	3.4	
Practical Stress, MPa	190	
Practical Kinetic Strain, %	3-5	
Standard Drive Current, mA	0.4	
Standard Power, W/m	8	
Linear Resistance, Ω/m	55	
Tensile Strength, N	18	
Weight, Per 200 mm Length, mN	223	
Contraction Time, s	1	
Relaxation Time, s	2	
Thermal Cycle Period, s	3	
Activation Temperature, °C	70	
	Martensite	Austenite
Density, g/cm³	6.45	6.45
Tensile Stress, MPa	1000	1000
Young Modulus, GPa	28	75
Thermal Conductivity, W/cm°C	0.08	0.18
Resistivity, μΩcm	76	82

TABLE 3. DESCRIPTIVE STATISTICS FOR FLEXINOL® 150LT AND BIOMETAL® 150

Descriptive	Flexinol® 150LT	Biometal® 150
Mean, mm	0.1495	0.1505
Median, mm	0.149	0.15
Std. Deviation	6.38×10^{-4}	6.95×10^{-4}

transformed to Austenite due to greater temperature of the actuator. Moreover, it was noted that the strains become consistent after initial loading cycles. Similar trend is noticed in Fig. 5 wherein Strain vs. Number of cycle graph is plotted for Biometal® 150.

When compared, Flexinol® 150LT actuators showed smaller strains as compared to Biometal® actuators (Figs. 4-5). Higher strains for the latter are explained by another graph which is plotted for drift against the number of cycles in Fig. 6.

The drift with respect to this study was defined as the displacement of actuator form the reference position. The reference was the position of the actuator before any activation current was applied to it. For instance, if laser sensor read 0.00 before actuator was heated for the first cycle and sensor read 0.02mm when actuator fully relaxed after heating and subsequent cooling then, drift was +0.02mm for the first cycle of operation. The positive drift indicated that actuator has elongated. Similarly, negative drift implied shortening of the actuator. In Fig. 6 the drift of Flexinol® 150LT actuators under both actuation voltages is nearly same. A very high and ever increasing drift was observed in the Biometal® actuators. The drift indicates permanent deformation of the Biometal® actuators and hence their inferior performance as compared to Flexinol® 150LT actuators.

5. CONCLUSIONS

In this research actuation characteristics of two 0.15mm diameter Ni-Ti based shape memory alloy wire actuators commercially available under the brand names of Flexinol® 150LT and Biometal® are investigated. Although, Biometal® actuators underwent larger strains as compared to Flexinol®150LT actutators but higher strains were produced at the cost of permanent deformation. This permanent deformation would result in non-repeatable actuation. Flexinol® 150LT actuators showed very little drift. Hence, on the basis of the results obtained in this research, the use of Flexinol® 150LT actuators is recommended for the cyclic applications.

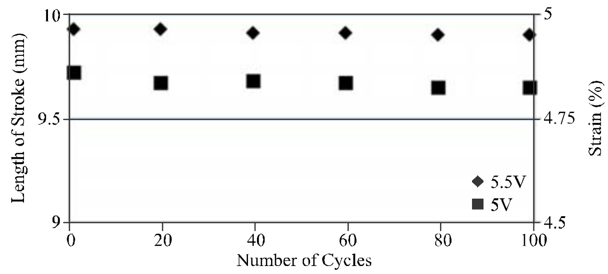

FIG. 4. STRAIN VERSUS LOADING CYCLE FOR FLEXINOL®150 LT

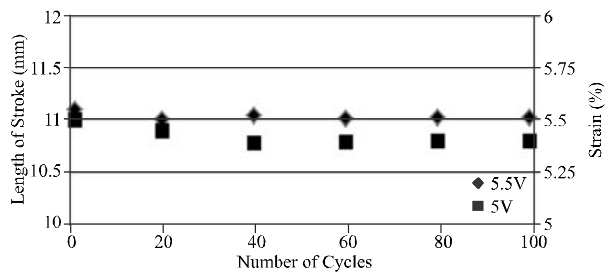

FIG. 5. STRAIN VERSUS LOADING CYCLE FOR BIOMETAL®

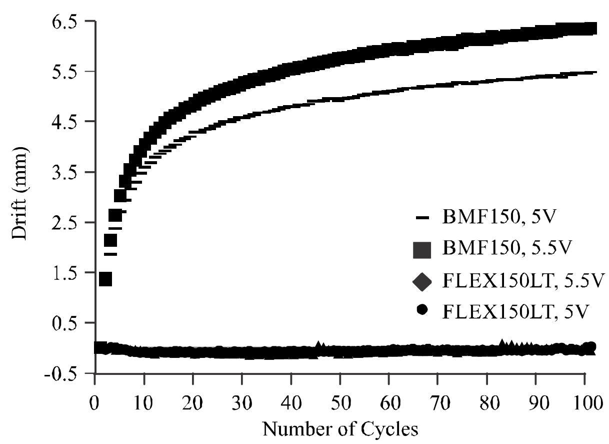

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FIG. 6. DRIFT OF ACTUATORS AT TWO DIFFERENT INPUT VOLTAGE LEVELS

TABLE 4. ACTUATORS USED IN SINGLE WIRE TESTS

Actuator	Diameter (mm)	Length (mm)	Bias Spring Rate (N/nm)	Initial Tension (N)	Actuation Time (s)	Cooling Time (s)
Flexinol® 150LT	0.14925	200	0.12	2	2	8
BMF® 150	0.1502	200	0.12	2	2	8

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