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Characterisation of 100 µm Diameter Shape Memory Alloy Actuators for Cyclic Applications

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Abstract: In this paper, the actuation behaviour of two commercially available shape memory alloy (SMA) actuators known as Flexinol and Biometal both having diameter of 100 µm is investigated under cyclic loading conditions. An experimental test rig was used to characterise the Nickel-Titanium (NiTi) based SMA actuators. Three different actuation voltages, 4.5 V, 5 V, 5.5 V, were used. The length of stroke and drift over one hundred cycles were measured for both types of actuators. The results showed that a higher actuation voltage result in higher length of stroke. Similarly, larger drift was observed for higher voltages. It was also found from the experimental results that Biometal actuators underwent larger drift than Flexinol actuators, this showed weaker resistance to permanent deformation for the former. It has been found from this research that Flexional actuators having diameters of 100 µm produced larger stroke and smaller drift than Biometal actuators under similar cyclic actuation conditions.

Keywords: Flexinol, Biometal, SMA, Characterisation, Cyclic Loading

1. INTRODUCTION

The high power-to-weight ratio, ease of actuation, noiseless operation and muscle like movement have made shape memory alloys (SMAs) a strong candidate for many smart actuation applications (Mavroidis et al., 2000). These applications include, but are not limited to, prosthetic hands, robotic grippers (specially microgrippers), minimally invasive surgery (MIS) and actuators used in space (Sreekumar et al., 2007). SMA actuated systems are light, compact and clean (Lagoudas, 2008). On the other hand, the use of conventional actuators like hydraulic, pneumatic and electric motors results in bulky designs (Mavroidis, 2002).

The research reported in this paper is part of the larger research in which bundled SMA actuators were used to actuate a robotic finger. The development of the bundle required that the actuator for the development of bundle to have good actuation properties under cyclic loading conditions. Hence, two commercially available equi-atomic Nickel Titanium actuators were tested for their actuation properties. Characterisation and comparative analysis of actuation properties of 100 µm diameter wire commercial actuators is an original contribution of this research.

2. MATERIAL AND METHODS

2.1 SHAPE MEMORY ALLOYS

The shape memory alloys belong to a group of alloys which exhibit shape memory effect (SME). SME is the property of a SMA that helps it to remember its high temperature phase. The Nickel Titanium based alloys possess better mechanical and actuation properties than other SMAs. They are not only biocompatible which makes them a strong candidate for biomedical applications but they can be actuated by various methods as well (Reynaerts, 1998). In low temperature phase, the alloy is in Martensite phase in which material is relatively soft (Zhong, 2006). When heated to the transformation temperature, Martensite transforms into parent structure known as Austenite. Austenite is a hard structure. The transformation in SMAs is thermomechanical. The heating results in the formation of Austenite which accompanies strain. Subsequent cooling transforms Austenite to twinned Martensite. A bias force deforms the twinned Martensite to detwinned Martensite. The SMA having detwinned Martensite phase is then ready for the next cycle of thermomechanical loading.

2.2 Test rig

An experimental set up (see Fig.1) was designed and developed to carry out tests on the actuators (Daudpoto, 2012). The rig used a force sensor, a laser displacement sensor and a temperature sensor. The actuator was heated by supplying electric power through a power amplifier. The software and hardware developed by National Instruments were used for data acquisition and generation of actuation signal.

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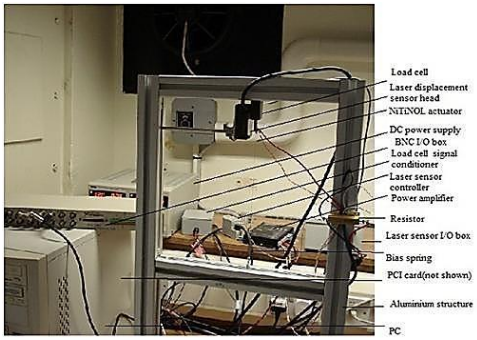


Fig 1. Test rig to characterise SMA wire actuators

2.3 ACTUATORS

In this paper, the NiTi based shape memory alloy actuators obtained from two leading manufacturers are investigated for their actuation characteristics. The US based Dynalloy Inc. produces the NiTi wire actuators under the commercial name of Flexinol (FLEX). The Japan based Toki Corp. produces NiTi wire actuators under the brand name of Biometal Fibre (BMF). The properties supplied by the manufacturers are presented in **Ошибка! Источник ссылки не найден.**. The transformation temperature for the Biometal actuator is 70 ^{0}C. The Flexinol actuator is supplied in two types, one is Low Temperature (LT) actuator which has transformation temperature of 70 ^{0}C and the other is High Temperature (HT) actuator that has transformation temperature of 90 ^{0}C. In this research, Flexinol LT version is used as it possesses the same transformation temperature (70 ^{0}C) as that of Biometal.

Table 1. Properties of Flexinol and Biometal actuators

Actuator	Avg. Diameter (µm)	Resistance (Ω/m)	Transformation Temp. (^{0}C)
FLEX100 LT	100	118	70
BMF100	100	135	70

In this research, Biometal and Flexinol actuators having diameters of 100 µm were used. Although, these actuators are also available in larger diameters but the time to cool off and the current required are large for them. For example, a 0.5 mm diameter Flexinol actuator requires 14 s cooling time and the 4 A actuation current.

2.4 METHODS

1. The diameters at ten different locations of five-metre long Flexinol and Biometal actuators were measured. The results are recorded in Table 2.

Table 2. Measurement on diameter of actuators

Measure	FLEX 100 LT	BMF 100
Mean, µm	98.9	101
Standard Deviation, µm	0.73	0.81
Minimum, µm	98	100
Maximum, µm	100	102
Count	10	10

For both actuators, mean was close to 100 µm and they showed very small standard deviations.

2. To prepare the test piece, wire actuators 210 mm long were cut. The 5 mm on each end were secured in the crimp terminals. The crimp tool was used to properly crimp the actuator. The proper crimping is very essential as slip between crimp terminal and actuator would result in inaccurate measurement of length of stroke and drift.
3. Initial tension for the actuator was set by adjusting the bottom support of the test rig. The initial tension was measured by load cell. For all actuators the initial tension of 2 N was applied by an extension spring having spring rate of 0.12 N/mm.
4. To capture the behaviour of the actuator under different electrical loadings, three levels of voltages were applied: 4.5 V, 5 V and 5.5 V. Voltage was applied by making a programme in LabVIEW environment. This signal was amplified by power amplifier and fed to the actuator. Actuation and cooling times were set as 2 s and 8 s, respectively. Actuators were cycled for 100 times.
5. Length of stroke was measured by recording the contraction measured by laser displacement sensor. To do this, a target for laser spot was attached to the lower end of actuator.
6. Drift was measured by measuring the difference of the position of target from the previous cycle when actuator was fully relaxed.

5. RESULTS AND DISCUSSIONS

Figures 2 and 3 show the lengths of stroke and drifts for the actuators respectively. Flexinol actuators showed higher lengths of stroke for all the actuation voltages (see Fig. 2). For actuation voltage of 4.5 V, Biometal actuators contracted for about 2 mm. The corresponding length of stroke for Flexinol actuators was about 4.5 mm. Both actuators showed nearly constant lengths of stroke throughout 100 cycles of loading for 4.5

V actuation. The actuation voltages of 5 V and 5.5 V resulted in larger stroke lengths for both Biometal and Flexinol actuators. The results confirmed that the higher heating power results in larger contraction. The higher actuation voltages did not show constant length of stroke over 100 cycles of operation. This was because of the permanent deformation in the actuators as evident from Fig. 3. For both actuators, higher voltages resulted in larger drifts. For all actuation voltages, Biometal actuators underwent larger drift which showed their vulnerability to permanent deformation.

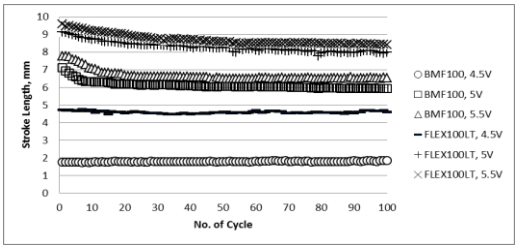


Fig. 2. Mean Stroke lengths for 100 µm diameter actuators

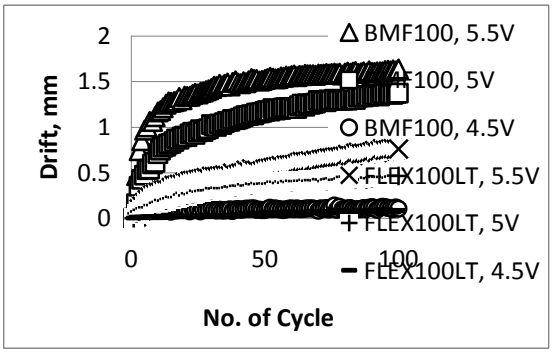


Fig. 3. Drift for 100 µm diameter actuators

In summary, results of the tests conducted on the two actuators showed that for 100 µm diameter, Flexinol actuators produced larger length of stroke as compared to Biometal actuators under identical loading condition. Moreover, Flexinol actuators also offered greater resistance to permanent deformation as compared to Biometal actuators. This was evident from the smaller drift for the Flexinol actuators.

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