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A Measurement Device for Bending Shape Memory Wire (BSW) Actuators

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Abstract. The shape memory wires are used as actuators for many applications. The purpose of this paper is to build a measurement device that could calculate the properties of bending shape memory wire actuators to find their activation temperature and generated force. The measurement device is build using the thermosensor and load cell, and it is controlled using LabVIEW. The device can test the bending shape-memory wires for (30,60, and 90 Degree). It is found that the diameter of the wire is the significant parameter that affects the generated force, while the folding angle did not affect the results. The activation temperatures for all wires are determined to be between (50-79 OC). The bending shape memory wire is the potential solution for self-folding robot applications.

Keywords: Shape Memory Alloy, Shape Memory Wire, Bending Shape Memory Wire, Measurement Device, Activation Temperature, Self-Folding Robot, Actuators.

Symbol	Meaning
SMA	Shape Memory Alloy
SMW	Shape Memory Wire
BSW	Bending Shape Memory Wire
VI	virtual instrument script
GUI	graphical user interface

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INTRODUCTION

The smart metallic alloys known as shape memory alloys can retain a particular shape or size before deformation. This process activated by heating the alloys to certain amount of temperatures [1]. The shape memory alloys have two crystal structures, the austenite which is the higher temperature phase, and the martensite which is the lower temperature phase. The transformation process between these two phases caused the memory of shape [2], See Fig. 1. The Young's modulus for Austenite is 75 GPa, and that for Martensite is 28 GPa [3]. At the Austenite, the high-temperature phase, the SMA becomes stiff and hard to deform. While the Martensite phase, the SMA can be deformed by applying a small amount of force. The SMA can be returned to its original shape when heated to a certain temperature, whatever its deformation at the Martensite phase. The process of heating can be applied by using a high-temperature environment or by direct electric heating, which is known as Joule's heating.

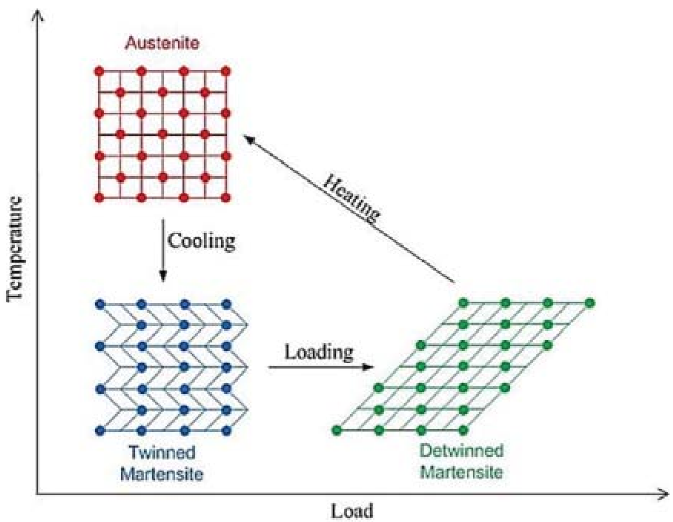


FIGURE 1. The shape memory alloys phase transformation [3].

The Nitinol is a type of SMAs that become a successful element in the engineering applications. It is also known as NiTi shape memory alloy. It is an alloy of 50%Titanium and 50% Nickel [4], and other elements can be added to enhance the properties [5][6]. The Nitinol alloys have the most significant potential to be actuators because they have many qualities such as high fatigue resistance under appropriate training, biocompatibility. They can heat by electricity, which makes the activation mechanism easy. Besides, they have the advantage of overall SMA actuators, such as a high work output, simplicity of design, silent and clean operation and miniaturization ease.

Recently, researchers are interested in building a morphing robot that could be self-folding [7][8]. This type of robot required a new type of actuator. A 3D printed hinge is used as a potential solution for connecting the elements of self-folding robots [9][10]. These hinges required an SMW actuator that could bend. Unfortunately, most SMW used as contraction actuators. For contraction SMW, the significant parameter that is calculated is the strain [3]. In this work, the bending shape memory wire actuator (BSW) is used. It is an SMW that has memorized bend angle, see Fig. 2. The properties of this type of actuator can be calculated by building a measurement device for (BSW) actuators. This device measures the force provided by BSW at different folding angles for different radiuses.

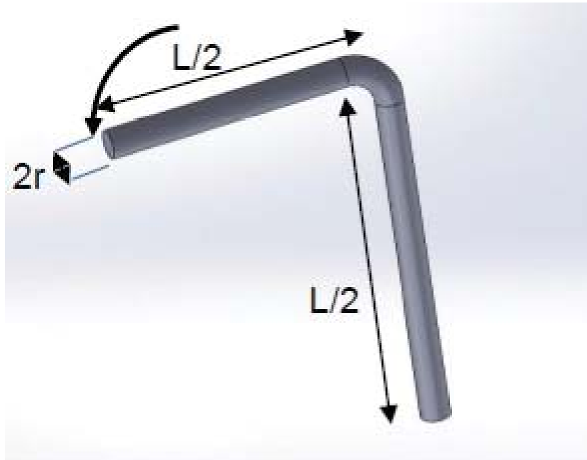


FIGURE 2 Design parameters of the BSW actuator.

Force Test Device (Parts & Setup)

The SMW actuators have important parameters that are required to be calculated. These parameters are the activation temperature and the applied force. Therefore, the device that measures these parameters should have a thermosensor to measure the temperature and a load cell to measure the force. The device has been built using a thermocouple type K and a flexible load cell and it is shown in Fig. 3. The load cell known as SingleTact load cell from the supplier SingleTact was used. SingleTact load cell has 1N of full-scale measure, and it could measure up to 300% from full scale with force resolution <0.2% of full scale. A 3D printed platform is used to fixed the load cell with a pad placed above it. The pad of the 3D printed platform can be replaced with another type that has a different angle to measure the applied forces for different folding angles, see Fig. 4.

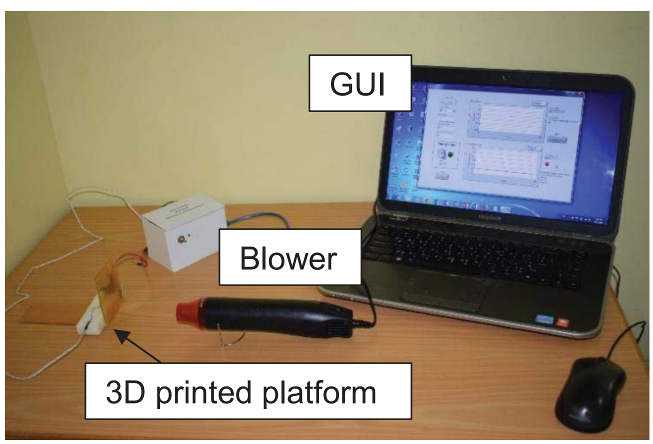
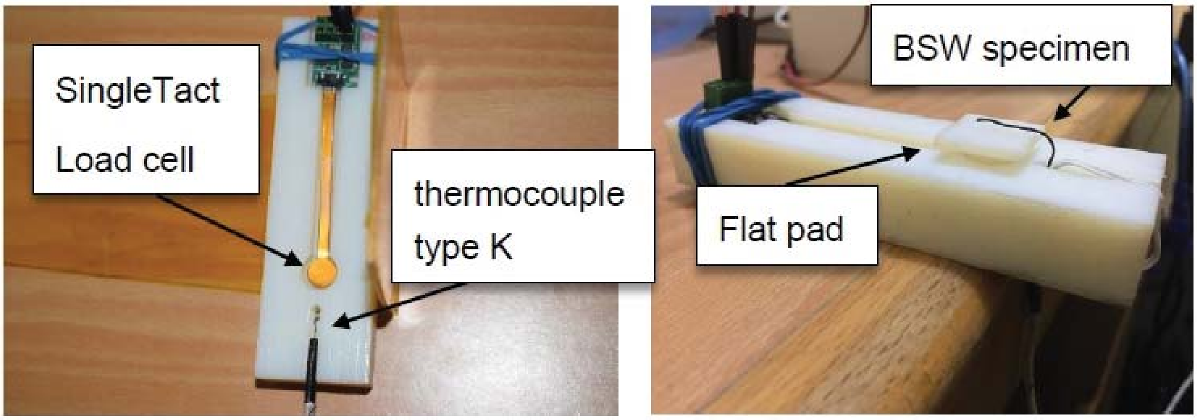


FIGURE 3 The measurement device for SMW actuators.



(a) (b)

FIGURE 4 (a)The 3D printed platform with load cell attached to it, and (b) The BSW actuator specimen with flat pad (90 folding angle).

The device used a type K thermocouple with 0^{o}C to 700^{o}C temperature range and has a 0.25^{o}C resolution. The MAX6675 junction is used to convert the analog signal to digital. The two sensors are connected to the Arduino, which is programmed to be compatible with the LabView software. The virtual instrument script (VI) was built using LabView software to collect and save the Excel file results. Fig. 5 shows the graphical user interface (GUI) of the VI program, displaying the force and temperature charts. Furthermore, it has a calibration button that resets the load cell measure's value to the original line.

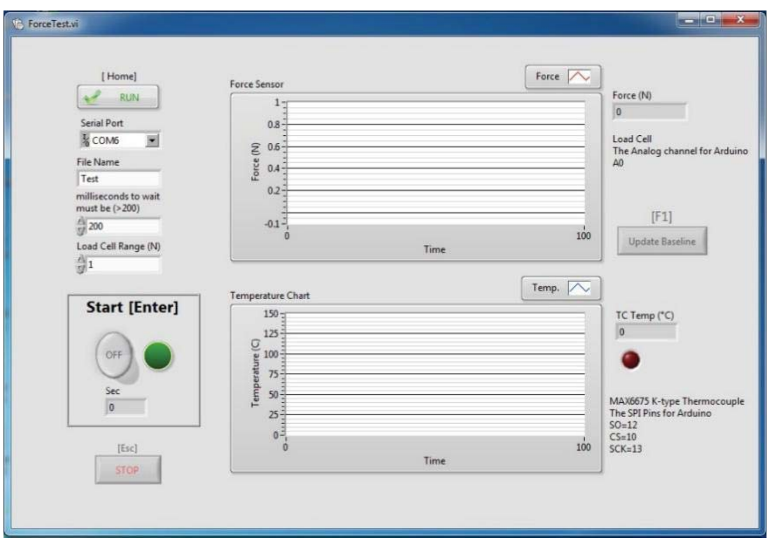


FIGURE 5 The measurement device Graphical User interface.

Test Procedure

The SMW that is used in this test was obtained from Kellogg's Research Labs Inc. This SMW is used for the fabrication of BSW actuators. The procedure to test these types of actuators with the force measurement device starts with choosing the appropriate angle of the pad. Three pads that have different angles are printed with the device. The angle of the pad is represented the angle of folding. The second step is to fix the BSW to the 3D printed platform, and the thermocouple should be attached to the specimen. The next step is heating the specimen to activate it. There are two ways to heating. The first one is by using direct electricity heating (Joule heating). The second way is by using a heated environment, and it can be applied by using a hot air blower that can provide air with temperature up to 200^{o} C. For the Joule heating, A Mosfet transistor is used to prevent short circuit damage.

All sensors were calibrated before use. The chilled water and boiling water were used to check the thermocouple. The thermocouple read 0.4^{o} -0.8^{o} C for chilled water and 100.6^{o} -101.3^{o} C for boiling water that gives an error range between 0.8 to 1.3%. The load cell's hysteresis was tested by using three loads (0.5, 0.7, and 0.9N), and the results are shown in Fig. 6. The maximum value of the hysteresis reached 6%.

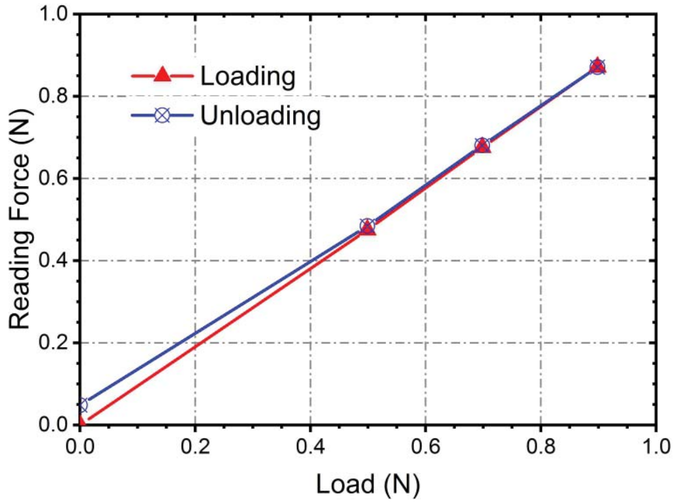


FIGURE 6 Hysteresis Test for the measurement device.

THE RESULTS

The relationship between the diameters and generated forces can be calculated by using three BSW wires with different diameters. (0.25mm, 0.5 mm, and 1 mm) are the sizes of the diameters. First, the test was applied for the three BSW specimens with 1mm diameters. The 90^{o} pad test was used to test these specimens and they were activated using hot air. Fig. 7 shows the results. The start activation temperature is between (52–56^{o} C), and the austenite finish temperature is between (73-77^{o} C). Furthermore, it is clear that the applied forces reach a steady state at 1N for the finish austenite temperatures.

To find the folding angle's effects on the generated force Nine BSW specimens were tested using different angle pads. Six specimens have a 1mm diameter, and the other three have a 0.5 mm diameter. They were tested using (30^{o},60^{o}, and 90^{o}) angles of folding pads and were activated using hot air. The results are shown in Fig. 8, which shows that there is a very slight difference between the amount of generated forces (less than 0.05N) at different folding angles. Furthermore, it is clear that the diameter of the wire has a large effect on generated forces. The generated forces are between (0.95-1.06N) when the diameter is 1mm. With a diameter of 0.5mm, the generated forces are between (0.45-0.51N).

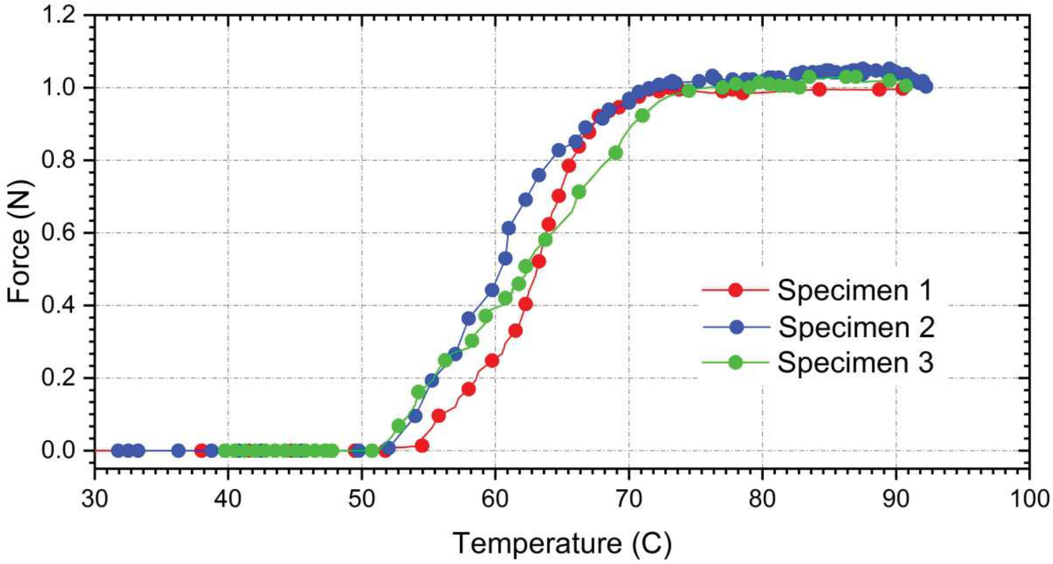


FIGURE 7 The BSW actuators activation curve for (1 mm Diameter, 90º folding angle) using hot air activation process.

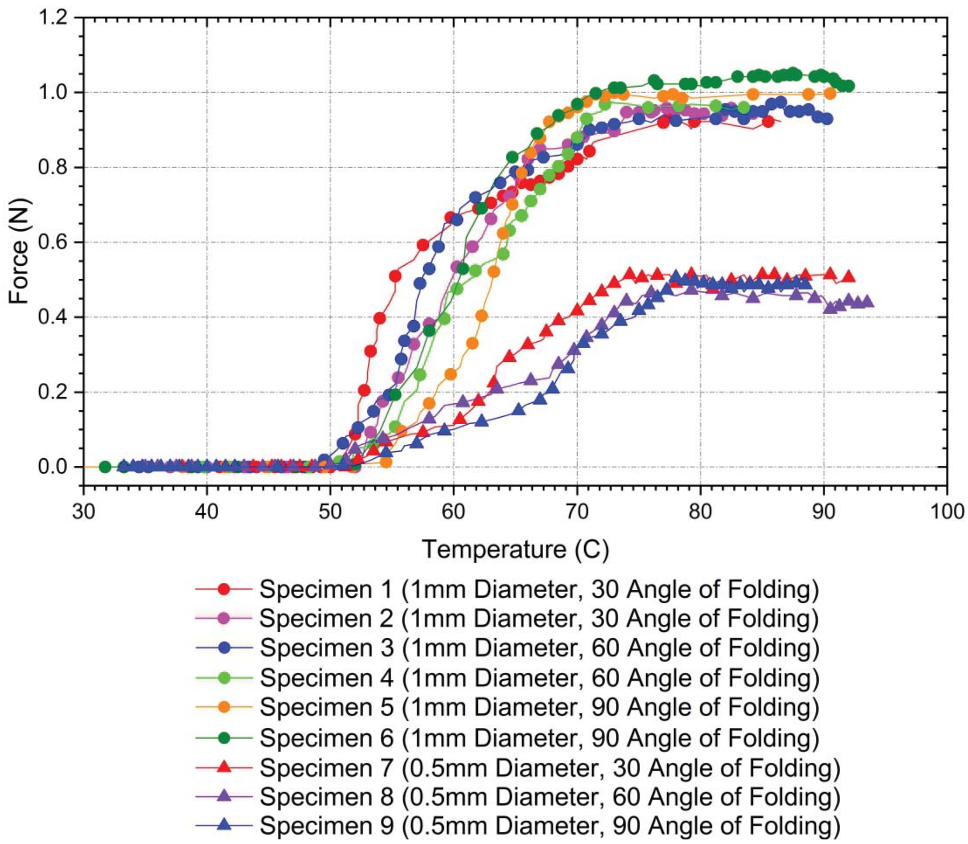


FIGURE 8 The BSW actuators activation curve for different folding angles using the hot air activation process.

The next test focused on the effect of the wire diameter on the generated force in BSW actuators. This test used four specimens. The 90-degree angles of the folding pad were used for the test and hot air activation was used as activation process. The results are shown in Fig. 9. When the size of the diameter is bigger the generated force is increased. The steady-state generated force for 0.25mm diameter is 0.2N and for 0.5mm diameter is 0.48N. The results show stability in the activation process for all diameter sizes, and they have nearly equal activation temperatures. The start activation temperature is between (51–54^{o} C) and the austenite finish temperature is between (72-78^{o} C).

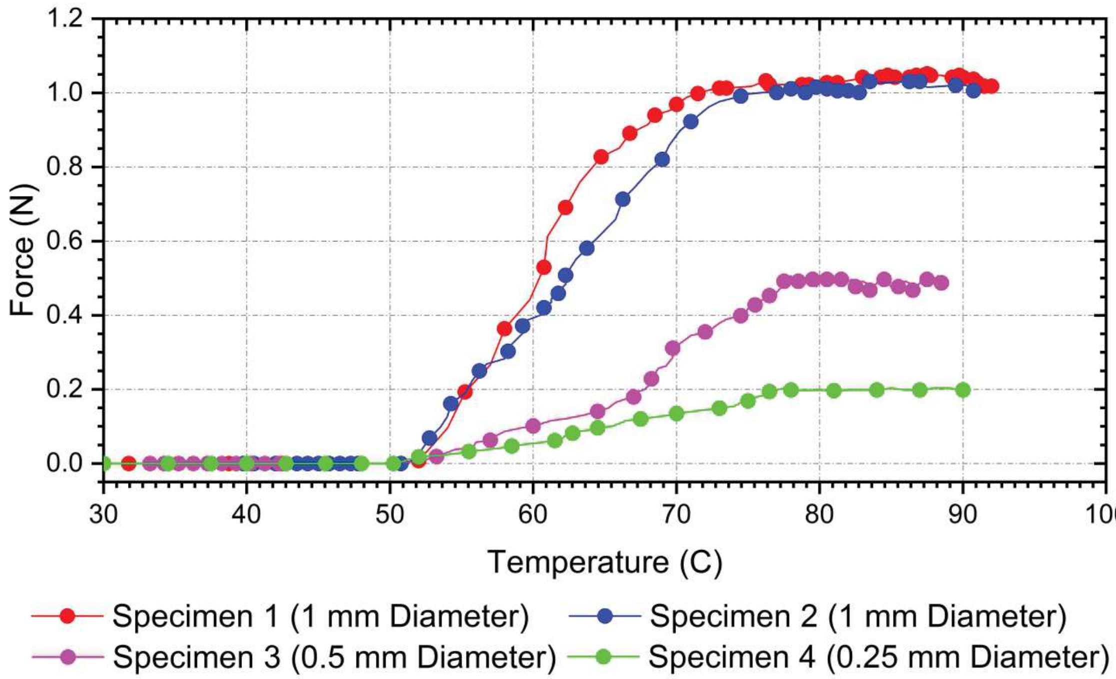


FIGURE 9 The BSW activation curve for the 90^{o} folding angle and different diameters sizes using hot air activation process.

The results show that the amount of generated forces for different folding angles is equal, and that is because the generated force was tested separately and without any external load in every angle of folding. The overall results of tests show that the wire diameter is a very effective parameter for determining generated forces, and other parameters have no effects or have minimal effects. The average generated forces are 1N, 0.45N, and 0.2N for 1mm, 0.5mm, and 0.25mm diameters of SMA wire. The range of start activation temperature is between (50–55^{o} C) and the range of austenite finish temperature is between (70-79^{o} C).

CONCLUSIONS

This paper concludes that the new measurement approach is required to calculate the parameters of the BSW actuators. The device of SMA force measurement was built to test the bending type of SMA actuators. Many tests have been applied to determine the generated forces for different angles of folding and BSW diameters. The results show that the activation temperature is between (50-79^{o}C), and the generated forces depend on the diameter of BSW. The BSW actuator type provides the same force for different angles in the same diameter when they are tested using hot air activation process.

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