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Research Article

Design and Construction of Analog Water Heater Chamber (AWHC) for Sma Rod and Spring Tensile Testing

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Abstract

This study details the design and construction of an Analog Water Heater Chamber (AWHC) specifically tailored for tensile testing of Shape Memory Alloy (SMA) rods and springs. The AWHC is designed to simulate various temperature conditions, enabling precise control over the thermo-mechanical behavior of SMA specimens. Energy conversion from the electrical to heat form is achieved using an electrical heating element of 1000 watts. This heat is transferred to the SMA spring/wire using convection using a water medium, and phase transformation occurs. The chamber's unique design allows for real-time monitoring of deformation and recovery processes under controlled temperature and loading conditions. Different test results for both the SMA rod and SMA spring at various loading rates and constant temperature, and continuous loading rate and different temperatures showed a good thermo-mechanical coupling result The AWHC's performance was validated through tensile testing of SMA rods and springs, demonstrating its efficacy in evaluating the mechanical properties and phase transformation temperatures of these materials. The results show excellent correlation with theoretical predictions, confirming the AWHC's suitability for characterizing SMA behavior under diverse thermal and mechanical conditions. This research contributes to the development of efficient testing protocols for SMA components, paving the way for their enhanced integration into various engineering applications, thus the aim of which AWHC is designed for is achieved.

Keywords

Water Bath Temperature, Shape Memory Alloys, Martensitic Transformation, Thermo-Mechanical Coupling

1. Introduction

Shape memory alloys (SMAs) have recently gotten extensive usage in many areas like aerospace, the medical field, and robotics because of their outstanding behaviors such as shape memory effect (SME) and pseudo elasticity (PE) [1]. Many ways are employed to test the behavior of this SMA wire of another geometry form from it like SMA spring SMA zigzag etc. The renowned one is tensile testing using electric DC. The electric current and the crystal transformation relationship of SMA under different loading define very well the tress-strain graph [2]. However, this method is a little bit complicated, and extra work needs to be done to study the effect of the ambient temperature. Another method is quasi-static tests, in this method, specimens were tested in a uniaxial screw-driven testing machine [3]. But all the testing is done at ambient temperature. Also in 2013, Jianzuo Ma et al used the conventional microwave to heat the SMA spring in their attempt to analyze the SMA spring testing characteristics actuation at different tempera-

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tures during loading and unloading, but in this approach, there is no cooling method for the system [4]. In this paper, a bath water testing method is presented with a very well-temperature-controlling system [5].

The physical property of a sample is measured as a function of temperature using Thermal Analysis Methods (TAM) by subjecting the sample to a controlled temperature program [6]. This includes the following: Electrical Resistance as a function of Temperature (ERT). In this non-destructive method, the NiTi SMA is placed into a thermally controlled silicon oil bath and subjected to a constant electrical current of intensity to cause a significant potential difference between any two points [7]. Another method is DSC is a thermal analysis apparatus that measures the physical properties of a sample SMA spring change, along with temperature against time [8]. In this research of SMA, the TAM mentioned above is adopted. By considering that water bathing is the cheapest method it subjects the whole material to temperature change at the same time and is the means for the final intended control of SMA, hence the AWHC is designed and fabricated based on it.

Water heating is a process of raising water temperature for a variety of uses, including residential, commercial, and industrial applications. As energy costs rise and environmental concerns grow, efficient water heating is increasingly important. This process is traditionally accomplished through electric or gas heaters, though modern technologies, such as heat pumps and solar water heaters, are becoming more popular due to their energy-saving potential and reduced environmental impact.

Types of Water Heaters

1. Conventional Water Heaters: These are tank-style heaters that store hot water for future use. They are typically powered by gas or electricity and remain popular for their relatively low upfront costs. However, they tend to consume more energy, as they continually maintain water temperature, even when not in immediate use [9].

2. Tankless Water Heaters: Tankless, or "on-demand" heaters, heat water only when needed, offering significant energy savings over tank-style models. By eliminating standby heat loss, they provide an efficient solution, though their installation costs can be higher [10].

3. Heat Pump Water Heaters: Heat pumps are a highly efficient alternative, especially in moderate climates, as they transfer heat from the surrounding air to heat the water. They use considerably less energy than traditional heaters and have a lower environmental impact [11].

4. Solar Water Heaters: Using solar energy, these heaters reduce reliance on conventional energy sources and minimize greenhouse gas emissions. Although they have a higher initial cost and depend on sunlight, solar water heaters are a sustainable choice for water heating in sunny regions [12].

5. Hybrid Water Heaters: Combining elements of traditional and heat pump systems, hybrid water heaters offer an efficient, versatile solution that adapts to varying energy requirements. They perform well in diverse conditions but have a higher initial investment than standard heaters [13].

Advancements in water heating technology have significantly improved energy efficiency, reducing both operational costs and environmental impact. Choosing the right type of water heater depends on factors like climate, hot water demand, and budget. Efficient water heating solutions are essential in lowering energy consumption and advancing sustainability goals. In this research, the conventional water heater is chosen to adopt.

2. Conceptual Design

The device is designed for heating water from ambient temperature up to 95 ℃ using an electric heating element. It consists of two chambers: the inner chamber where the heating element, and temperature sensors are inserted, and the outer chamber. This outer chamber is divided into two sides: the upper and lower sides. The upper which takes about 80%, contains insulating materials against conduction and radiation. The lower side contains accessories like a pump and other electrical connections. A thermostat and Thermal Analysis Methods (TAM) digital thermometer are also mounted to regulate and measure the inner temperature respectively. The inner chamber has four outlets, two for in and out water flow; and the other two for inserting the specimen under test (SMA rod or spring). A standing made of PVC fitting is designed for holding the device at upright position while not in use.

2.1. Heat Require to Heat the Inner Chamber

Heat capacity is defined as the energy in Joules required to raise the temperature of an object by 1 ℃. This is referred to specific heat of an object. It is formulated as:

Heat capacity = mass x specific heat x change in temperature

$$Q = mC\,\Delta T \tag{1}$$

Where Q = heat capacity in Joules (J), m = mass in kg, C = specific heat of an object, (4.19 KJ/Kg ℃), ΔT = change in temperature [14].

$$Q = mC(T_2 - T_1) = \rho VC(T_2 - T_1) \tag{2}$$

Where V is the volume of the water; ρ = density kg/m^3. For water, ρ=1000 kg/m^3; the inner chamber volume is V_{inner} =1 litre; C =4.19 KJ/Kg ℃; T_1=18 ℃; T_2= 90 ℃, Q is calculated as 301,680 J.

But power is heat energy per time for the volume of the water to be heated (sec).

$$P = \frac{Q}{t} \tag{3}$$

Hence, assuming 5 minute for water to be heated to 90 ℃

$$P = \frac{Q}{t} = \frac{301,680}{300} = 1005.6 \text{ watt}$$

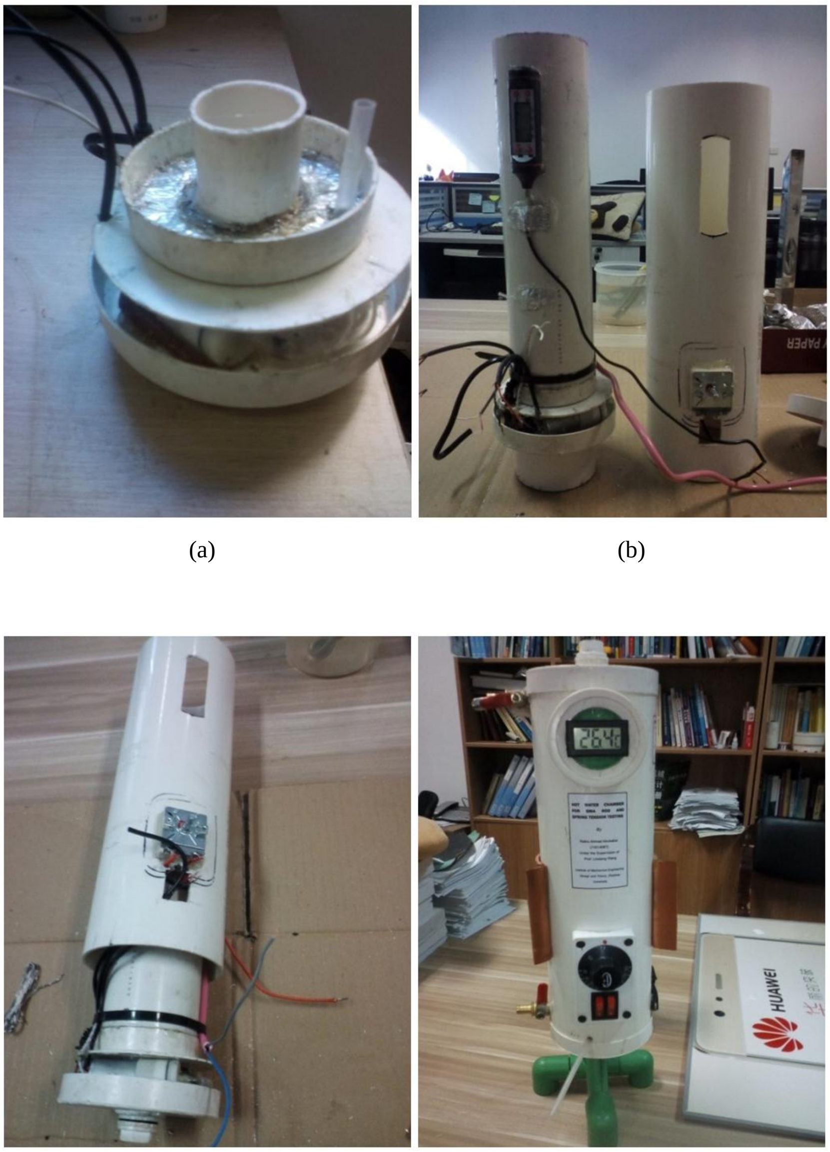
Therefore, 1000 watt heating element is used, connected in series with an analog thermostat for temperature regulating setting.

2.2. Water Stirring

While heating is taking place inside the inner chamber, the water is stirred by circulating the water from the bottom of the chamber to the top for efficient mixing and equal distribution of temperature. This is achieved a using small DC water pump. The circulation of the water has to be done thoroughly every half minute. Hence the mass flow rate for the pump is taken as 2 liter/minute and the pump is selected based on the following parameter: head = 350 mm, flow rate = 2 liter/min, size, working temperature = 100 ℃. Based on the above, a water pump with model: P3001 is selected and purchased [15]. The thermal is provided by inserting coating wool in between the two chambers.

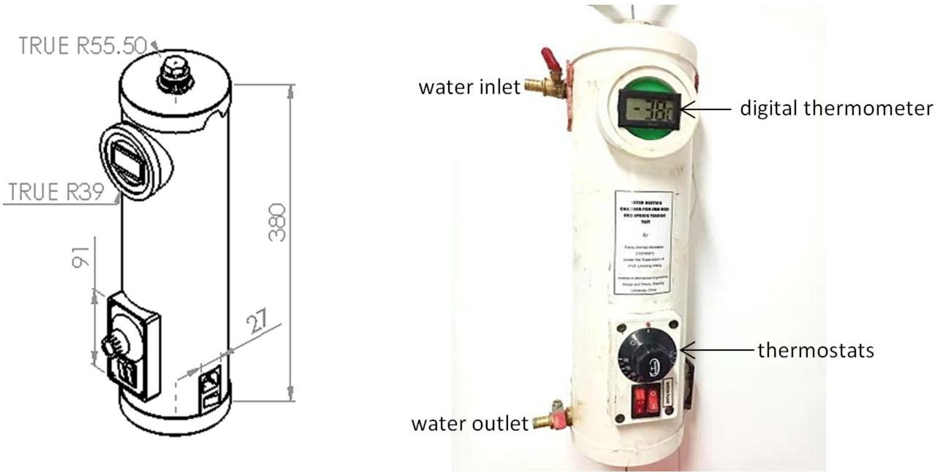
3. Construction

Figure 1 shows the AWHC at different construction stages. The material used is PVC pipe.



(a) (b)

(c) (d)



(e) (f)

Figure 1. (a) base (b) first and second chamber (c) first chamber inserted into the second chamber (d) AWHC on the stand (e) Solid work drawing (f) after constructed.

4. Experiment Test

Experimental tests are performed to test the performance of AHWC. The additional instruments used include the following: A tensile testing device (height: 1150 mm) constructed for this purpose, which has a loading cell (HF0-500 N), and a computer laptop computer set. Six active coils of the SMA spring are cut and hooked at both ends to two steel wires, as shown in Figure 2. The steel wires with the SMA spring are inserted into AHWC through its top and bottom opening. The AWHC is mounted onto a tensile tension machine, with the steel wires gripped onto the gripper of the tension test machine. The experimental setup is shown in Figure 2.

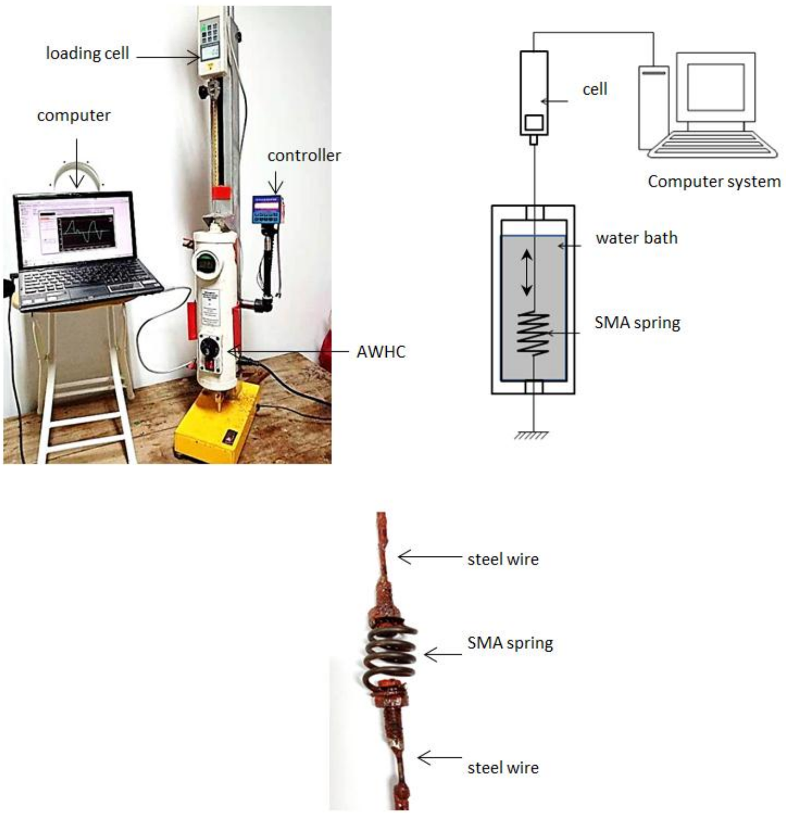
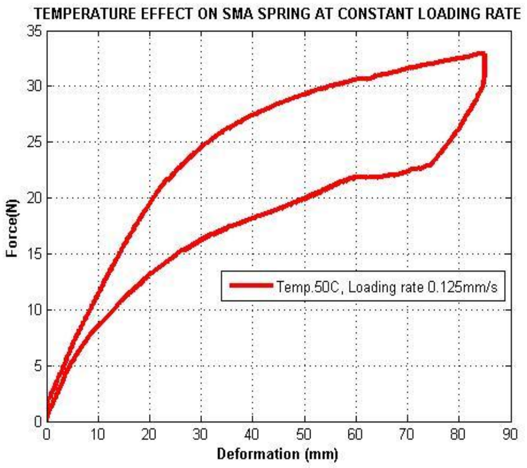


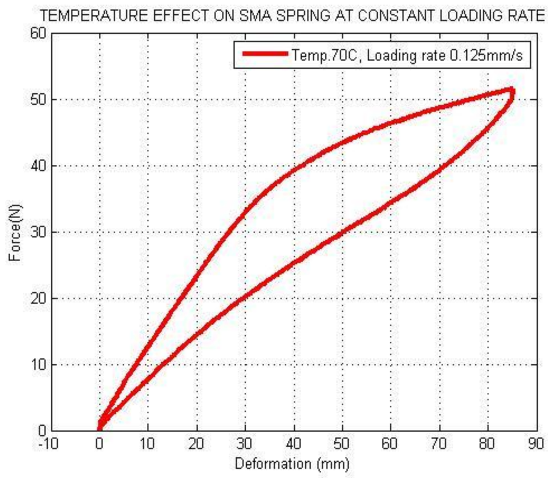
Figure 2. Experimental setups for AHWC.

4.1. Result for SMA Spring

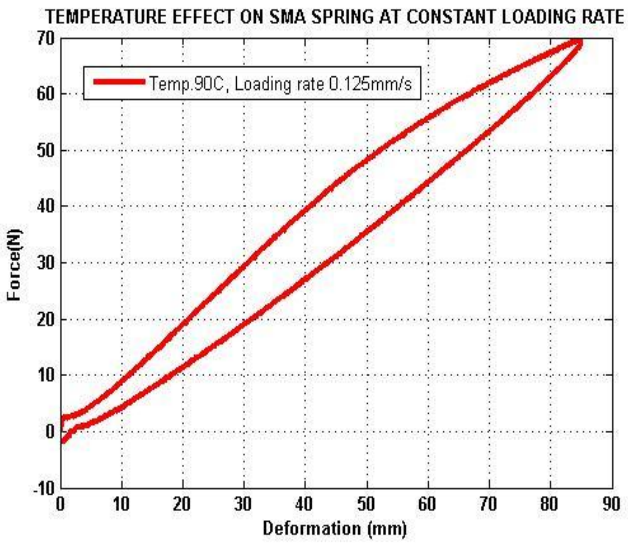
Here the graphical results SMA spring are presented in Figure 3.



(a)



(b)



(c)

Figure 3. *(a) SMA spring heating at 50 ℃ (b) SMA spring heating at 70 ℃ (c) SMA spring heating at 90 ℃.*

4.2. Result for SMA Rod

The SMA rod is inserted into the AWHC and mounted onto a tensile testing machine for tensile testing at constant temperature and different loading rates, and the result is shown in Figure 4:

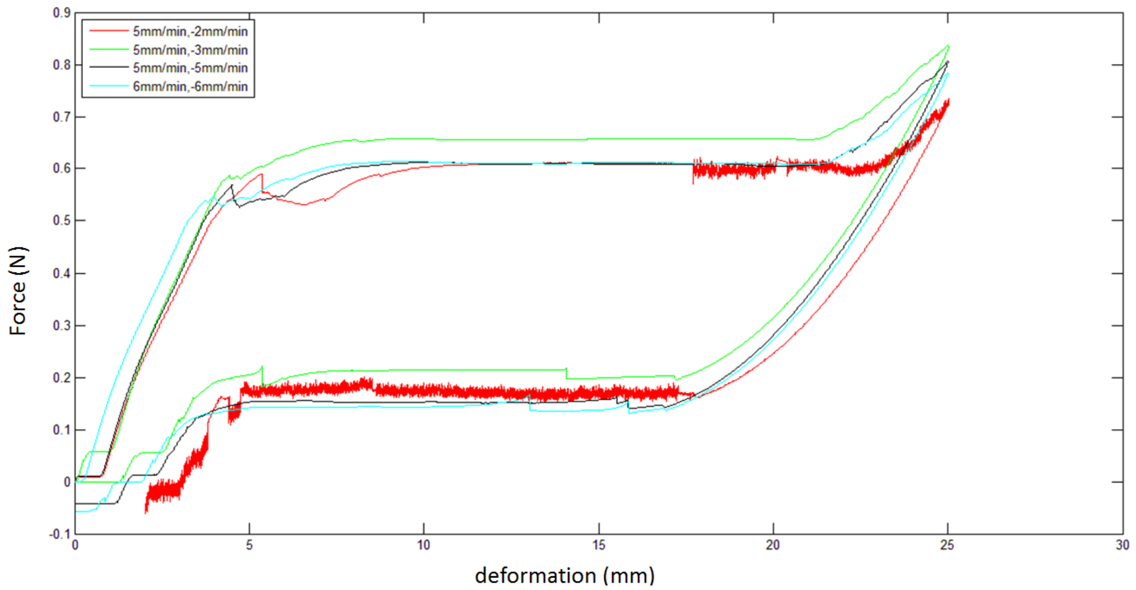


Figure 4. *SMA rod at a constant heating temperature of 6 ℃ but different loading rate.*

4.3. Result Discussion

The experimental graphs show that when the temperature is above the critical temperature and not so high, the SMA structure's pseudoelasticity is observed. The hysteresis loops have a horizontal plateau during both the loading and unloading process which is easily explained by the martensite-austenite phase transformation inducement in SMA structures. But at a higher temperature, 90 ℃, with the same loading, the hysteresis loops occur with no horizontal plateau during the loading and unloading processes. This fact is easily explained by the theory that at high temperatures, the coupled thermoplastic property of the SMA structure is more pronounced, and the effect of the martensite-austenite phase transition becomes more.

5. Conclusion

The successful design and construction of the Analog Water Heater Chamber (AWHC) marks a significant milestone in the development of a cost-effective and efficient testing apparatus for Shape Memory Alloy (SMA) rod and spring tensile testing. The AWHC's ability to simulate various temperature conditions, coupled with its precision control over heating and cooling rates, enables accurate and reliable tensile testing of SMA specimens. The AWHC's performance has demonstrated exceptional consistency and repeatability, making it an ideal platform for characterizing the mechanical properties of SMA materials. The chamber's design allows for easy modification and adaptation to accommodate different SMA configurations, ensuring its versatility for future research applications. Key findings from this study include: 1-Effective temperature control within ±1 ℃ of the set point. 2-Uniform heating and cooling rates, ensuring minimal thermal gradients. 3-Successful tensile testing of SMA rod and spring specimens.

The AWHC offers several advantages over traditional testing methods, including: 1-Reduced energy consumption. 2-Increased testing efficiency. 3-Enhanced accuracy and precision. 4-Compact design, suitable for laboratory settings. This research contributes significantly to the field of materials science and engineering, particularly in the development of SMA-based applications. The AWHC's design and construction provide a valuable resource for researchers, engineers, and industries seeking to characterize and optimize SMA materials for various applications, such as aerospace, biomedical, and automotive engineering.

Future studies can leverage the AWHC to investigate the effects of temperature, strain rate, and other environmental factors on SMA behavior, further expanding our understanding of these versatile materials. Recommendations for Future Work: 1-Investigate the application of AWHC in testing other shape memory materials. 2-Develop advanced control algorithms for improved temperature control. 3-Explore the scalability of the AWHC design for larger SMA specimens. By advancing the understanding and characterization of SMA materials, this research paves the way for innovative solutions in various engineering disciplines.

Abbreviations

AWHC	Analog Water Heater Chamber
SMA	Shape Memory Alloys
ERT	Electrical Resistance as a Function of Temperature
TAM	Thermal Analysis Methods
LCD	Liquid Crystal Display

Author Contributions

Rabiu Ahmad Abubakar is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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