CHARACTERIZATION OF ACTIVE SHAPE CONTROL SMAHCS UNDER THE INFLUENCE OF VARIOUS AMBIENT TEMPERATURES

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ABSTRACT

In this work four shape memory alloy hybrid composites (SMAHC) with different geometry for active shape control were characterized under the influence of different ambient temperatures. For this purpose, the actuators were thermally activated by Joule heating. In the investigated ambient temperature range of -10 °C to +45 °C, the functionality could be verified for all actuators and relationships between bandwidth, energy consumption, deflection, ambient temperature and the structural parameters could be determined. Thermomechanical characterizations similar to [1],[2] were carried out. Due to the high weight specific performance as well as the macroscopic stroke, SMAs are particularly suitable for the implementation of new systems in aviation [3],[4]. Because the thermal activation of SMAs is associated with low efficiency, incorrect design may therefore result in an energy requirement that may not be met by the host system. The studies conducted here are intended to provide the basis for estimating energy requirements over a wide temperature range and thus define a useful baseline for many applications for SMAHCs.

1 INTRODUCTION

Shape memory alloy hybrid composites (SMAHC) are a class of smart composites with the ability to change their shape in response to external stimuli such as heat or electric current, due to the thermoelastic phase transition of embedded filaments of a shape memory alloy. The basic concept was proposed in the early 90s by [5], [6] to control vibration and acoustic or vibrational properties. Other applications include manipulating thermal buckling behavior of restrained composite components [7], [8] or its impact behavior [9]. If the SMA filament is positioned out of the neutral axis, it can be used for bending actuation in a so-called "unimorph" configuration [10]. Extensive experimental characterization and theoretical description of the thermo-elastic phase transition of the SMA can be found, e.g., in [11]. However, it was concluded that there needs to be more experimental data available for SMAHCs actively modifying the shape [12]. As the activation of the phase transition is initiated by increasing the temperature above the material-specific transition temperature, the SMAHC actuators can be activated reasonably fast. The deactivation process is controlled by conductive or convective heat transfer, and therefore activation cycle is limited to approx. 20 Hz. The heat losses towards the environment are the reason for the rather low energy efficiency of SMA-driven actuators in the range of 1 % and the necessity of taking the thermal aspect of the actuation process precisely into account during the design phase of an application.

Due to the SMA wires' contraction during thermoelastic phase transition from martensitic to austenitic phase, induced by Joule heating the SMAHC bending deformation occurs. Without an external force, this results in a constant curvature along the SMAHC´s substrate axis, which mathematically can be described with a circular arc with a bending radius. SMAHC is often configured as a cantilever with one end constrained without any degree of freedom and the opposite end freely movable. At temperatures below martensite finish temperature, the actuator is in its initial state. Activation starts above austenite start temperature AS. Maximum activation is reached at austenite finish temperature AF. These temperatures increase with applied mechanical stress [11]. The bending shape essentially depends on the stiffness of the substrate, the distance between the neutral axis of the substrate and the SMA layer, and the SMA performance. In addition, external loads can have a large influence on the actuator's deflection. The distance between the SMA layer and the neutral fiber of the substrate can be referred to as the actuator's gear. The performance of the SMA layer depends on the material characteristics and the density of wires in the layer. More wires in one layer cause a higher stiffness and bending potential of the SMAHC but also come with higher energy consumption.

2 Material & Method

The studied SMAHCs (compare Fig. 1 and 2) consisted of three main components and were based on a prototype of an active vortex generator already tested in flight [3]. The base substrate was spring steel, an overlying flexible layer out of elastomer and the SMA grid. The SMA wires were aligned along the x-axis. Shear forces at the wire ends are transferred to the substrate via the crimp bar with frictional and form-fitting interlocking.

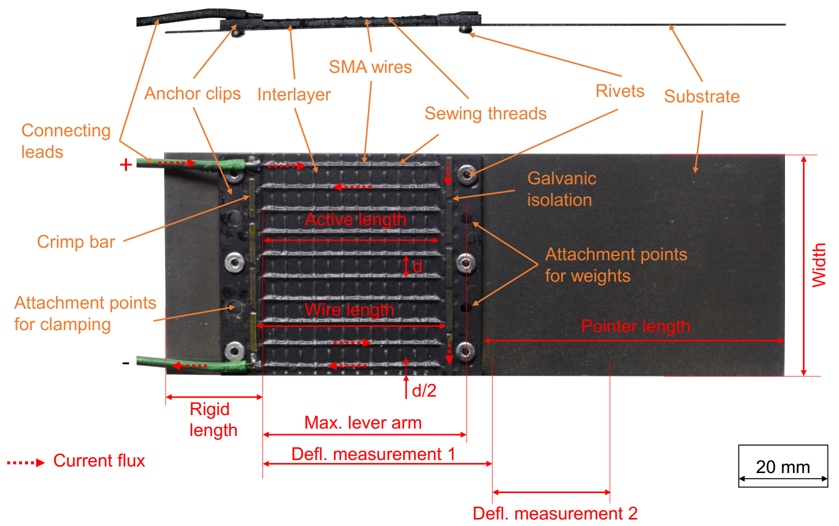

Figure 1: Side- and top view of the investigated SMAHC assembly.

The SMAHC deformation is limited to the length of the SMA wires between the crimp bars which is referred to as active length. The SMA grid is realized with a centerline distance between the parallel wires of 5mm. SMA wires were made of trained Smartflex® NiTi-alloy material, made by SAES Getters. The active length of the actuator was 39 mm. Four different types of actuators were studied which differ in both, the thickness of elastomer layer as well as of base substrate, according to table 1. The width of the actuator was 50 mm. There were 10 SMA wires in one grid and one grid per actuator.The SMA grid was designed as an electrical circuit. The crimp bar was cut at specific points for galvanic isolation to ensure a series connection of the SMAs and uniform electric current in all wire segments. The actuator's surface was painted with black ink with a specified emission coefficient, allowing temperature measurement using thermal imaging of the SMA wires. Additionally, a speckle pattern was sprayed on the surface of the actuator using white paint. The speckle pattern generated a grayscale map on the surface to enable digital image correlation (DIC).

Type		Elastomer thickness in mm	Laminate thickness in mm
A		2.4	0.45
B		1.8	0.45
C		1.2	0.45
D		2.4	0.50

Table 1: Actuator types and varied parameters

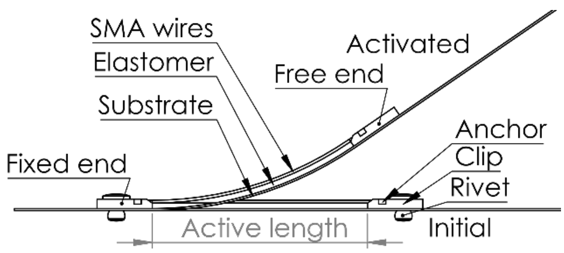

Figure 2: SMAHC assembly in initial and activated state.

The thermoelastic phase transformation of the embedded SMA wires was initiated via Joule heating with an electric current of up to 5.0 A. Each specimen used was first cycled 10 times at room temperature. The test process comprised 4 sub-steps. First, the specimen was fixed on the test table and then conditioned for 20 minutes at the respective ambient temperature, followed by cycling of the actuator. Each cycle consisted of the thermal activation of the SMAs by means of Joule heat loss through a fixed electrical current. The activation was stopped as soon as either the SMAs reached 130 °C, or after 100 s at the latest. Afterwards, the current was cut off and the actor cooled back down for 30 minutes. This cycle was repeated for various electrical currents, starting from 0.5 A up to 5.0 A in steps of 0.5 A. Each setup, which was composed of ambient temperature and actuator type, was repeated with 3 samples. During cycling, the SMAHC's tip deflection was measured using a laser triangulation distance sensor (Panasonic HG-C 1200-P) and the temperature by infrared measurement (Micro Epsilon TIM 640 VGA with microscope optic) of the painted SMA wire's surface. Voltage drop over the SMA grid as well as the electric current were also measured. For statistical purposes, experiments with the identical setup were combined to evaluate mean value and confidence interval. Student distribution was assumed due to the small number of independent experiments.

3 Results & Discussion

Figure 3 shows the heating behavior of the four actuator types with additional consideration of the ambient temperature, using a heating current of 2.5 A as an example for the actuator type A. The deflection is normalized for the different SMAHC types A - D, using the maximum deflection reached with the respective actuator.

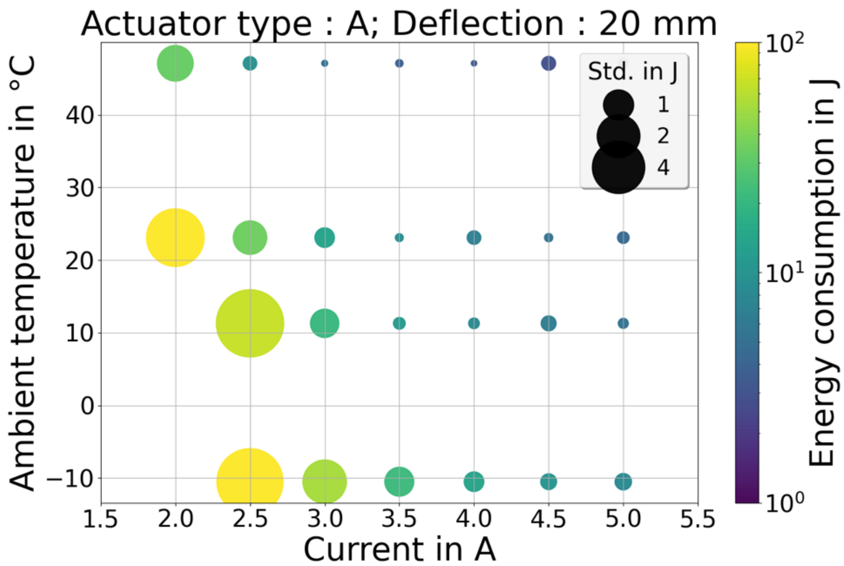

Figure 3: For the same actuator type the energy consumption to reach a deflection of 20 mm for various el. currents and ambient temperatures is evaluated.

In addition, parameter fields were developed which provide information about how fast a required actuation can take place under given circumstances. In Figure 4 for all four actuator types A to D, the correlation between the normalized deflection and the activation time for a activation current of 2.5 A is given for the four ambient temperatures -10.5 °C, 23.1 °C, 11.3 °C and 47.1 °C.

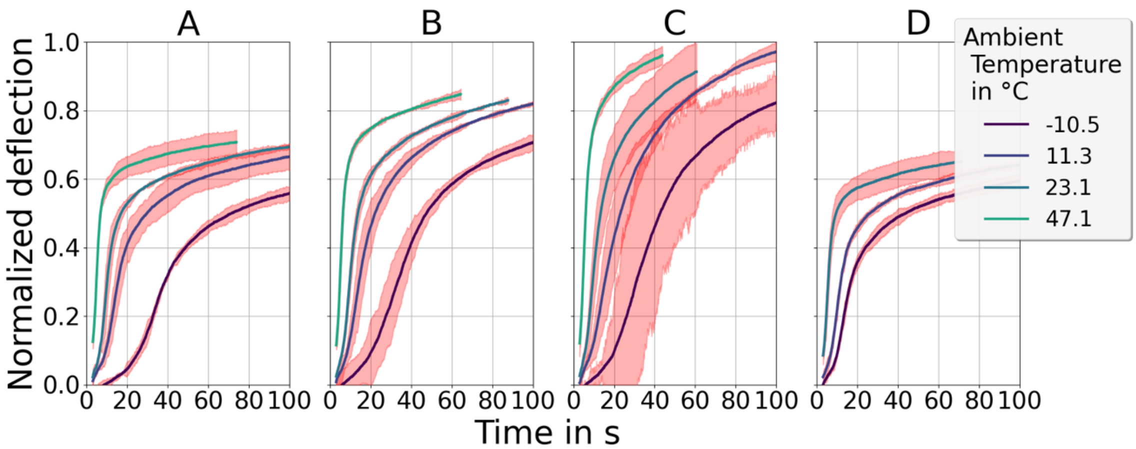

Figure 4: Correlation between the normalized deflection and the activation time for a current of 2.5 A. Taking into account the ambient temperature as well as the actuator type.

Figure 5 depicts the correlation between electric current, ambient temperature and SMAHC deflection, as an example for actuator type A and activation time of 5 s. From this diagram the energy consumption can be deduced.

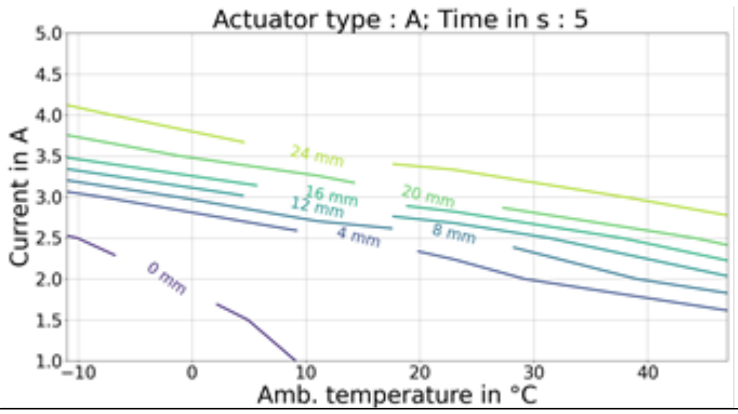

Figure 5: Correlation between el. current, ambient temperature and deflection for actuator of type A and activation time of 5 s.

4 Conclusion

An extensive experimental characterization of the electro-thermo-elastic behavior of SMAHC actuators for shape adaption under the influence of various ambient temperatures was presented. Results allow for the correlation between elastomer/laminate layer thickness, energy consumption, ambient temperature, electric current and deflection. Particular focus lays on the effect of the interlayer's material thickness and the substrate's stiffness on the actuator performance. The achievable bandwidth of the SMAHC is significantly influenced by the ambient temperature. More electric energy is required at low ambient temperatures to achieve the same actuator deflection in a specified time. The results presented here were used to develop and validate a transient electro- thermomechanical model of the SMAHC [13] investigated here experimentally. The model outperforms current models. The transient shape change can be anticipated while considering design factors and boundary conditions. To support future design efforts, based on SMAHC it is implemented without proprietary software, therefore accessibility to the research and engineering community is guaranteed [14]. The underlying dataset can be found here [15].

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