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Proxy of a Ti-Ni Shape memory alloy Actuators Based on Recurrent Neural Networks

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INTRODUCTION & AIM

Advancements in fields like aerospace and medicine demand materials with highly specific properties, making conventional options unsuitable. **Functional materials**, particularly Nickel-Titanium **(Ni-Ti) smart alloys**, are promising due to their unique **ability to change properties in response to stimuli like temperature**.
However, using them effectively requires understanding their complex behavior, and current experimental methods are slow and expensive. Analytical modeling is also challenging due to the phenomenon's complexity.
This work proposes a data-driven, **machine learning (ML) proxy model to overcome these limitations**. By using time series data, the model will infer the hysteresis curve and phase transformation in Ni-Ti actuators.
The goal is to reduce development time and costs by creating an efficient predictive tool. This involves a comparative study of **LSTM, GRU, and CNN neural network architectures** to identify the most effective model for analyzing the actuator's performance.

METHOD

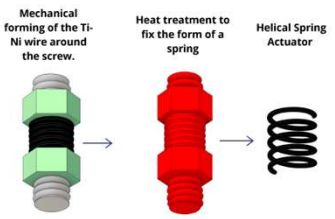

Figure 1: Fabrication (a), shaping (b), and geometry fixing of the actuator (c).

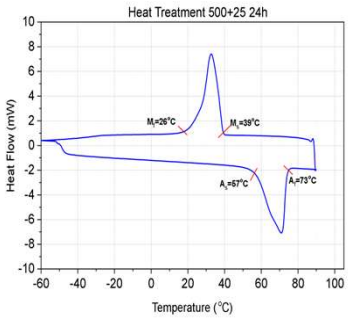

Figure 2: Calorimetry Results for the Material.

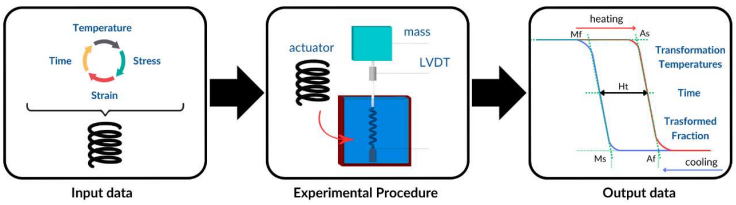

Figure 3: High fidelity: Experimental procedure.

These procedures demand significant preparation, involving substantial time consuming, materials, equipment preparation, which can make the research quite costly.

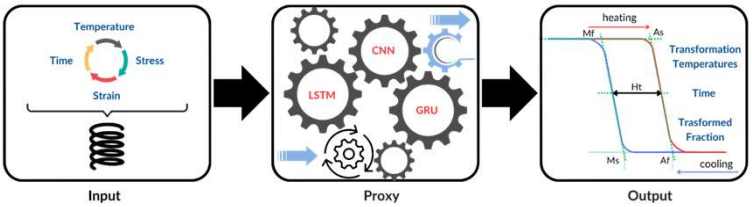

Figure 4: Proxy model using LSTM, GRU or CNN for actuator behavior prediction.

The inputs include time series of temperature controls, applied loads, and material characteristics, while the outputs correspond to the hysteresis curves during cooling and heating.

RESULTS & DISCUSSION

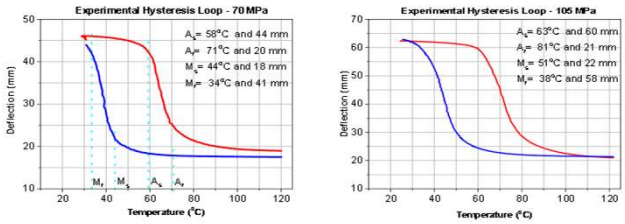

Figure 6: Experimental Results for 70 MPa and 105 MPa Shear Stress.

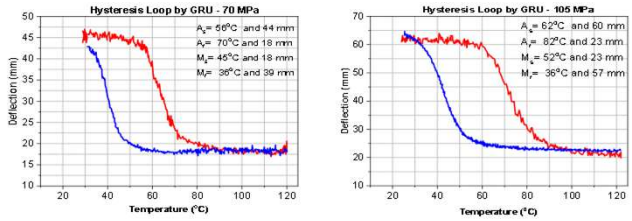

Figure 7: Results for GRU Technique for 70 MPa and 105 MPa Shear Stress.

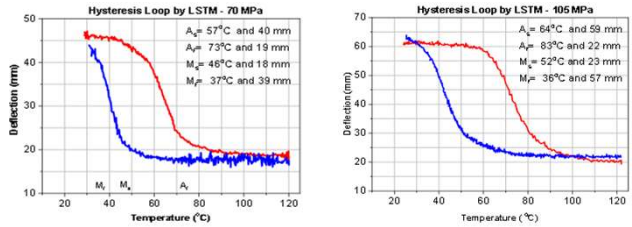

Figure 8: Results for LSTM Technique for 70 MPa and 105 MPa Shear Stress.

Table 1: Comparison strategies to 70 MPa

Strategies	Trainable parameters	Number of epochs	RMSE %
LSTM	546515	25	1.3
GRU	192165	18	0.9
CNN	547291	22	1.5

Table 1: compares the results obtained by the three proposed strategies, including the number of hyperparameters, number of epochs, and RMSE for each technique.

Table 2: Comparison strategies to 105 MPa

Strategies	Trainable parameters	Number of epochs	RMSE %
LSTM	287232	29	1.6
GRU	376232	21	1.4
CNN	1133024	20	1.2

Table 2: compares the results obtained from the three proposed strategies, including the number of hyperparameters used in the process, the number of epochs, and the RMSE for each technique.

CONCLUSION

Experimental results show that the heat treatment applied to the Ti-50.4at%Ni alloy effectively activated the martensitic and austenitic phase transformations;

The proxy models demonstrated strong performance, with Root Mean Squared Errors (RMSE) below 2% in all cases. The GRU architecture achieved the lowest error, 0.9%, for the 70 MPa stress, also standing out for requiring fewer parameters and less training time. The CNN architecture showed better results for the 135 MPa stress, indicating an advantage in more complex contexts.

Partially or fully replacing traditional experimental procedures with machine learning-based proxy models can significantly reduce time (over 1500 hours) and costs while maintaining the quality of system response predictions.

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