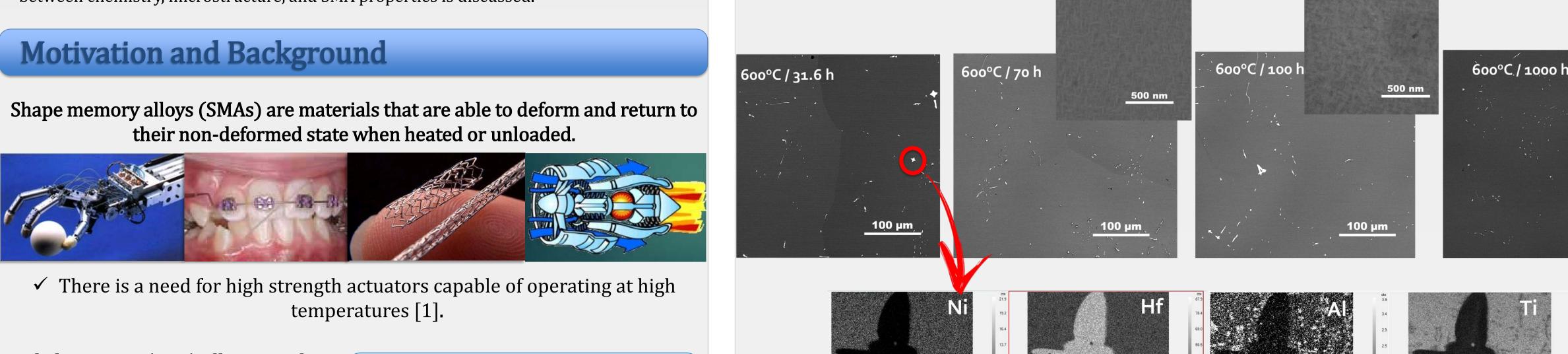


# Design and characterization of a NiTiHfAl precipitation strengthened SMA

### Abstract

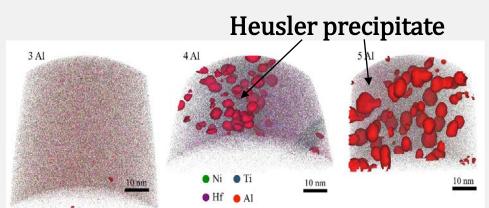
Shape memory alloys (SMAs) have unique behavior and wide commercial application. A quaternary NiTiHfAl SMA was designed to achieve a good combination of high phase transformation temperature (>100°C) and improved strength, compared to binary NiTi. The addition of Al can produce the strengthening Ni<sub>2</sub>TiAl Heusler nano precipitate, but depresses the transformation temperature in solution. This drawback can be compensated by Hf addition. Precipitation strengthening improves thermal fatigue life, output force and shape memory effect, increasing critical stress for martensite slip rather than detwinning. In this study, induction melted 50Ni-21Ti-25Hf-4Al alloy aged at different temperatures and mechanical properties were evaluated using Vickers Hardness testing. Microstructural evolution and phase characterization were performed using Scanning and Transmission Electron Microscopy (SEM and TEM), X-ray Diffraction (XRD) and Electron Probe Micro-analyzer (EPMA), respectively. The relationship between chemistry, microstructure, and SMA properties is discussed.

their non-deformed state when heated or unloaded.

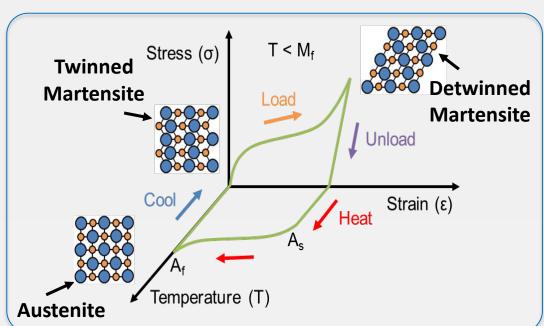


#### Nickel-titanium (NiTi) alloys stand out among SMAs for their:

- $\checkmark$  superior ductility;
- ✓ greater recoverable strain;
- $\checkmark$  excellent corrosion resistance;
- ✓ stable transformation temperatures;
- ✓ biocompatibility and electrical properties;
- ✓ favorable power-to-weight ratio.



Atom probe from an aged  $Ni_{50}Ti_{30-x}Hf_{20}Al_x$  (x=3,4,5) alloy [4]



Visual representation of the thermo-mechanically driven crystallographic changes displayed in SMAs [2]

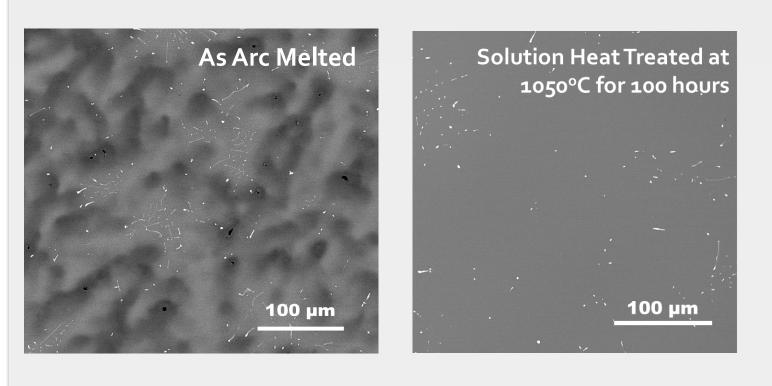
#### **Precipitation Strengthening:**

- Increase work output  $\rightarrow$  improve strength + decrease irrecoverable strain
- Precipitates  $\rightarrow$  barriers to dislocations
- Dislocation slip should be more difficult than twin boundary movements

Experimental Procedure				
(*Followed by oil quenching)				
Arc Melted	Heat Treatments*		Characterization Steps	
$Ni_{50}Ti_{21}Hf_{25}Al_{4}$ (at.%)	Solution	Aging	Microstructural Analysis	
	1050°C	600°C	SEM	TEM
	<ul><li>✓ 100 h</li></ul>	31.6 h 70 h 100 h 1000 h	Phase Identification	
			EDS/WDS	XRD
			Mechanical Properties	
			Vicker Hardness	

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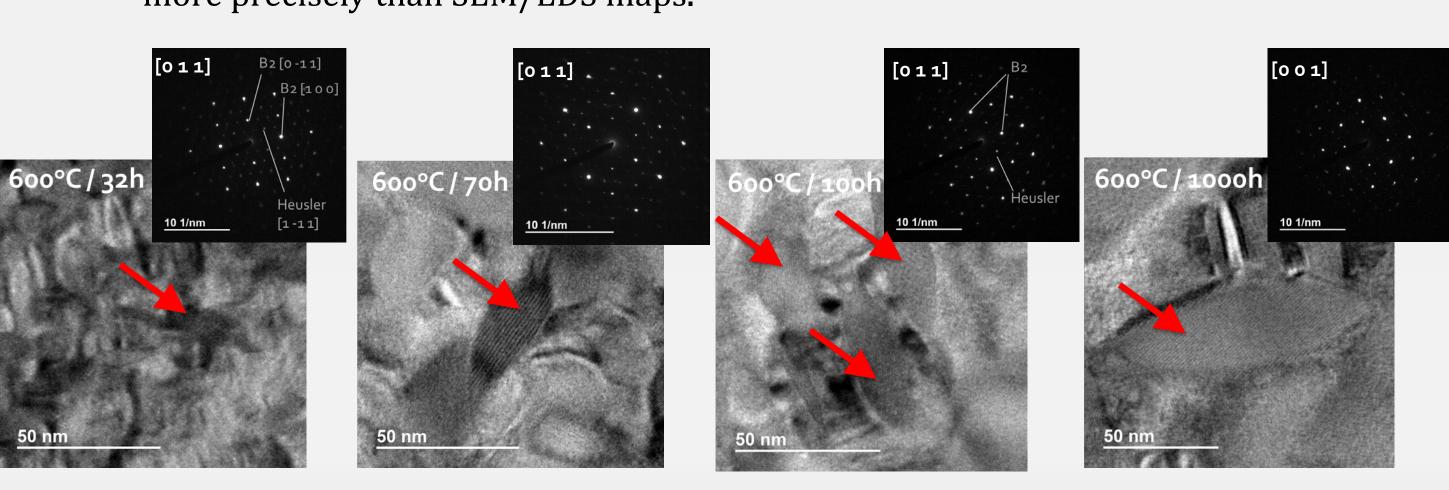
## **Microstructure and Precipitation Evolution**



**SEM / BSE images** showing a homogenous NiTi matrix with some undissolved interdendritic Hf rich phase [bright contrast] after the solution heat treatment.

For the aged material, no changes in the matrix. Insets show high magnification LV-**SEM images** that allows to observe the nanoscale precipitation structure

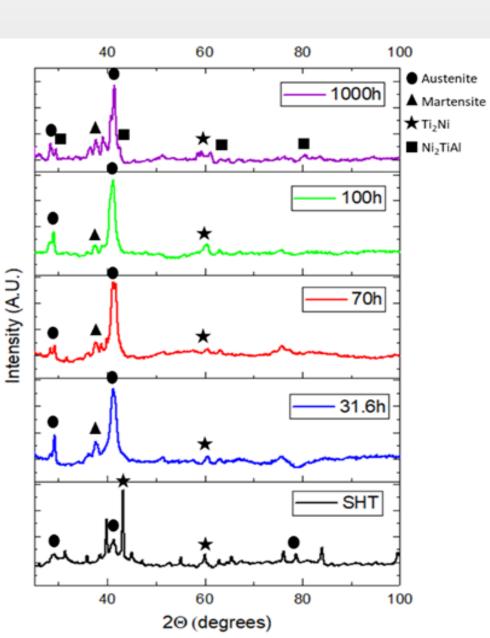
**EPMA / WDS 2D element maps** showing quantitative analysis of the Hf rich phase (>92 at%) and smaller precipitates distributed in the matrix ( $Ti_2Ni$ ), more precisely than SEM/EDS maps.

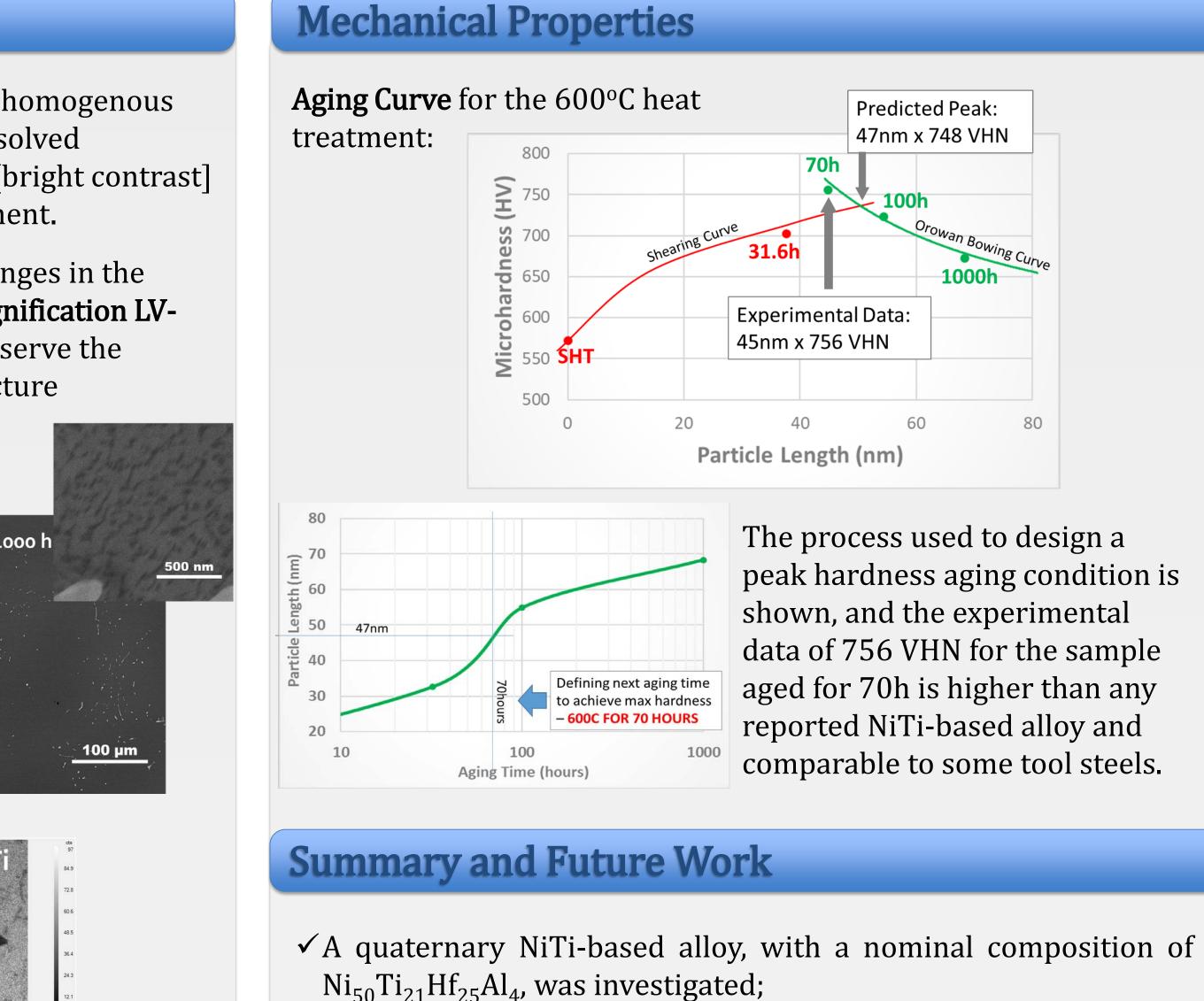


**HRTEM images** of the nanoscale Ni<sub>2</sub>TiAl L2<sub>1</sub> Heusler precipitation evolution. Insets show **SAED patterns**.

## **Phase Identification**

**XRD patterns** of the solutionized material and the samples aged at 600°C for 32h.,70h., 100h., 100h. showing phase evolution. The results show a mainly B2 NiTi structure, in all the samples, with some Ti<sub>2</sub>Ni phase present. The Heusler phase peaks are intense enough in the sample overaged for 1000 hours, which had a more coarsened precipitation structure.





# References

Future work:

of treatment;

[1] A. Nespoli, S. Besseghini, S. Pittaccio, E. Villa, S. Viscuso, Sensors and Actuators a-Physical, 158 (2010)

bearings and other mechanical components.

[2] Wayman, C.M. "Shape Memory Alloys." MRS Bulletin Apr (1993): 49-56. [3] J. Jung: Design of Nanodispersion Strengthened TiNi-base Shape Memory Alloys, in Materials Science and Engineering. 2003, Northwestern University: Evanston [4] D.H.D. Hsu, B. Hornbuckle, B. Vaderrama, F. Barrie, H.B. Henderson, G.B. Thompson, M.V. Manuel, "The Effect of Aluminum Additions on the Thermal, Microstructural, and Mechanical Behavior of NiTiHf Shape Memory Alloys," Journal of Alloys and Compounds, Accepted and In Press.

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