SHAPE MEMORY ALLOY ACTUATORS:
Optimisation by Fatigue and Thermal Management

Tamer Ataalla

School of Aerospace, Mechanical and Manufacturing Engineering
RMIT

Supervisor: Dr Martin Leary
Secondary Supervisor: Professor Aleksandar Subic

ABSTRACT

Shape Memory Alloys(SMAs) provide a significant opportunity for **lightweight**, environmentally friendly actuators if the inherent limitations of the heat transfer rate can be overcome.

In this project a novel method is proposed to **optimise the fatigue life and cooling rate** of Shape Memory Alloy actuators.

PRESENTATION OVERVIEW

- Introduction
- SMA Attributes
- Limitations
- Project Aims
- Procedure (Experimental, Analytical & Numerical)
- Applications
- Conclusions & Future Work
- References

INTRODUCTION

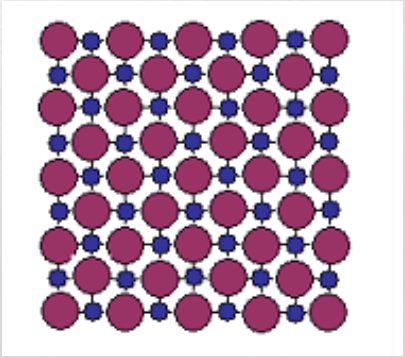
- ***What is shape memory alloy?***
  - A shape memory alloy (SMA, memory alloy, muscle wire, smart alloy) is an alloy that undergoes a *solid phase transformation*.
  - An SMA "remembers" its original, cold-forged shape returning the pre-deformed shape by heating.
- ***When was it discovered?***
  - First discovered by Arne Olander who found unique properties in Gold-cadmium alloys in 1932 [1].
  - It was not utilized until 1962 by the US Naval Ordnance Laboratory [1].

PHASE TRANSFORMATION

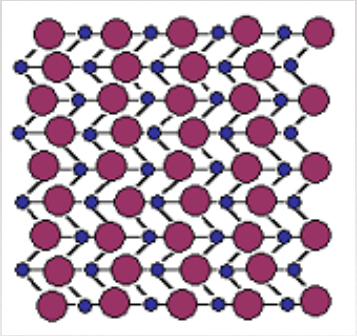
Two distinct phases

high temperature:
austenite

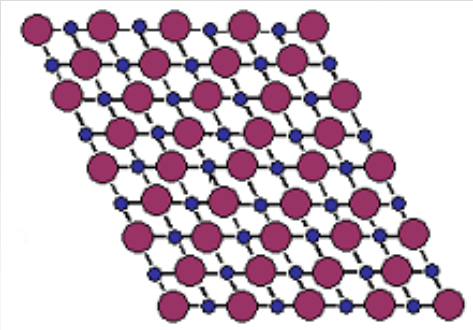
low temperature:
martensite



Austenite



Twinned Martensite



Detwinned Martensite

BENEFITS

- **Mass reduction**
- Reduced manufacturing complexity
- Reduced cost (compared to traditional solinoids, etc...)
- **Power to weight ratio is very high**
- Enhanced functionality?
- No noise, (less distraction to driver)
- Contribution to fuel efficiency (Fuel economy) via reduced mass (Small contribution). Hence a reduction in greenhouse gases.
- Shape memory alloy actuators produce one of the highest stresses among all actuators that have ever been developed [3].
  - For example, Nickel-Titanium SMAs have an actuation stress of over 200MPa, 570 times larger than the human muscle.
- **Novel technology which would enhance the position of Australia's automotive industry**

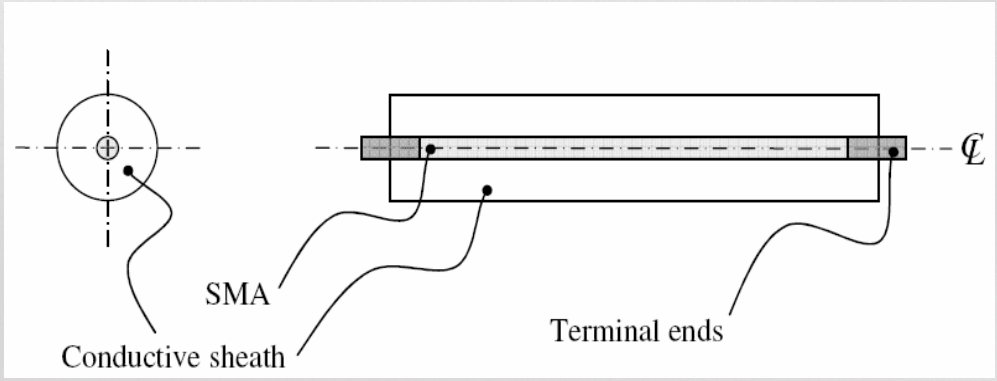
LIMITATIONS

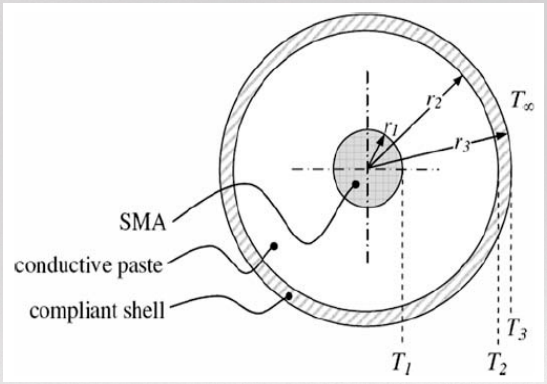
- Very quick actuation response, but inherent slow cooling rate
- Fatigue life unknown… How many cycles an SMA wire can survive.
- Automotive seating system… design constraints and space restriction.

PROJECT AIMS

- Find optimal conditions
- Lagged Vs Unlagged (New)
- Optimise and Implement
- Acoustic testing

PROPOSED COOLING METHOD

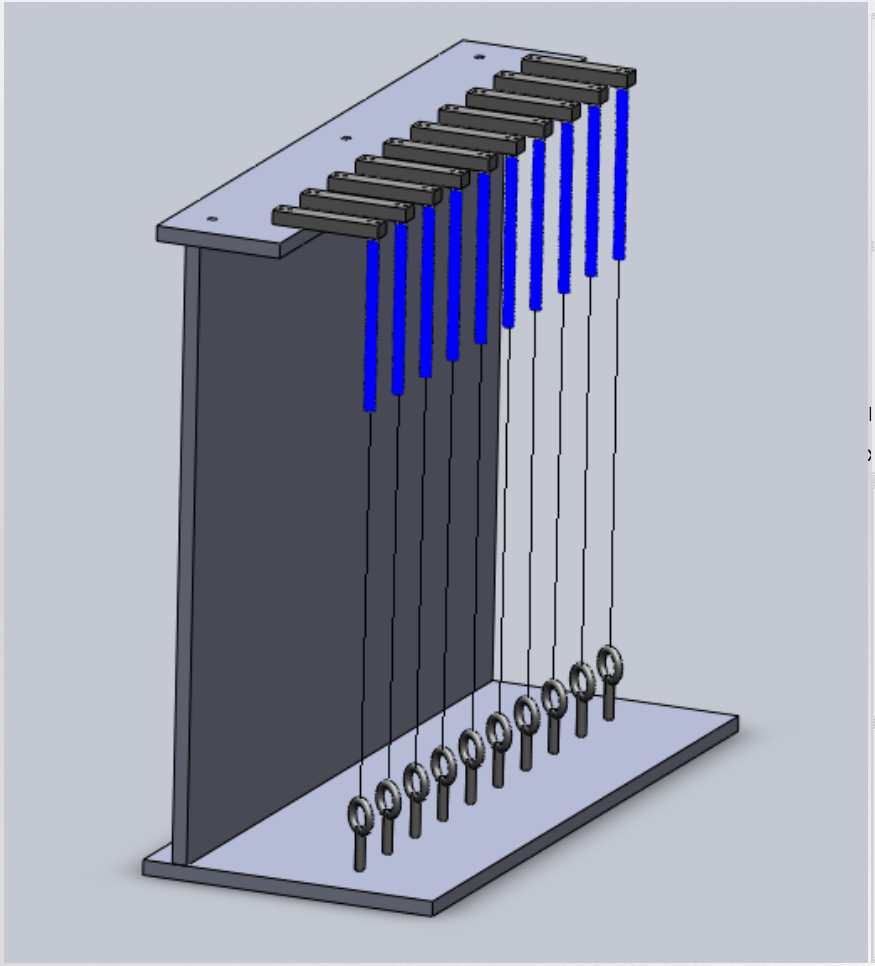


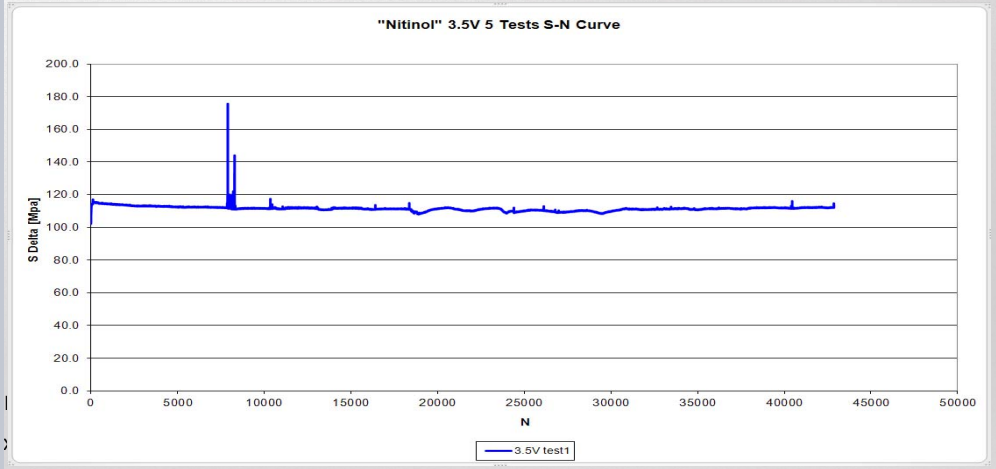


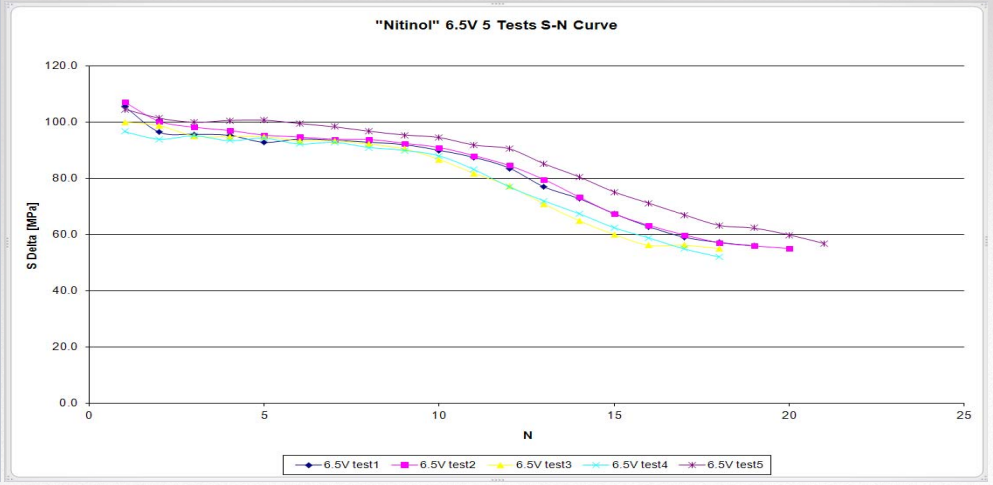
PROCEDURE

- Experimental:
  - S-N Curve
  - Functional Vs Structural fatigue
  - Lagged Vs Unlagged
- Analytical:
  - Finite Difference Method (FDM)
- Numerical:
  - Finite Element Method (FEM)

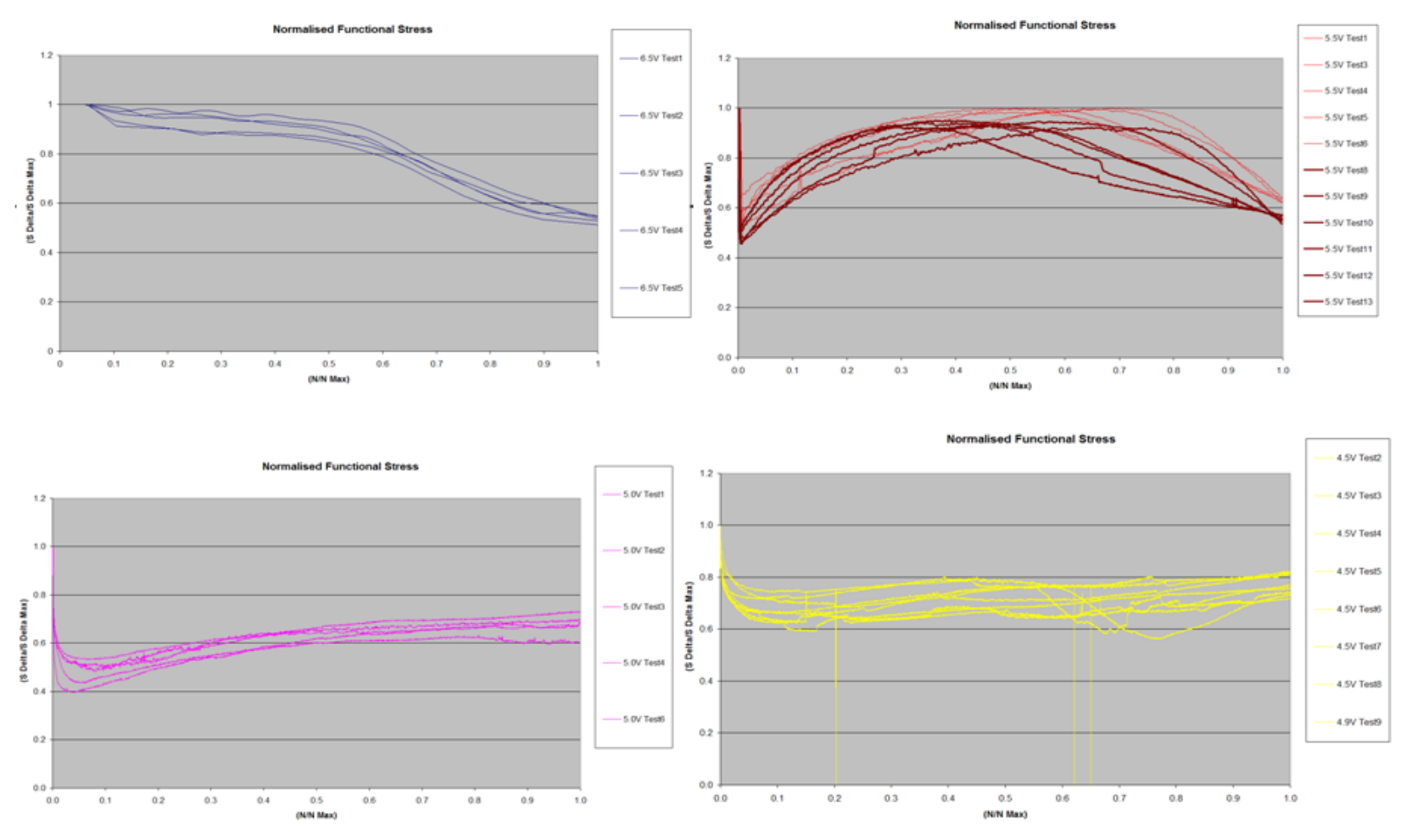
EXPERIMENT: Multi Load Cell Rig



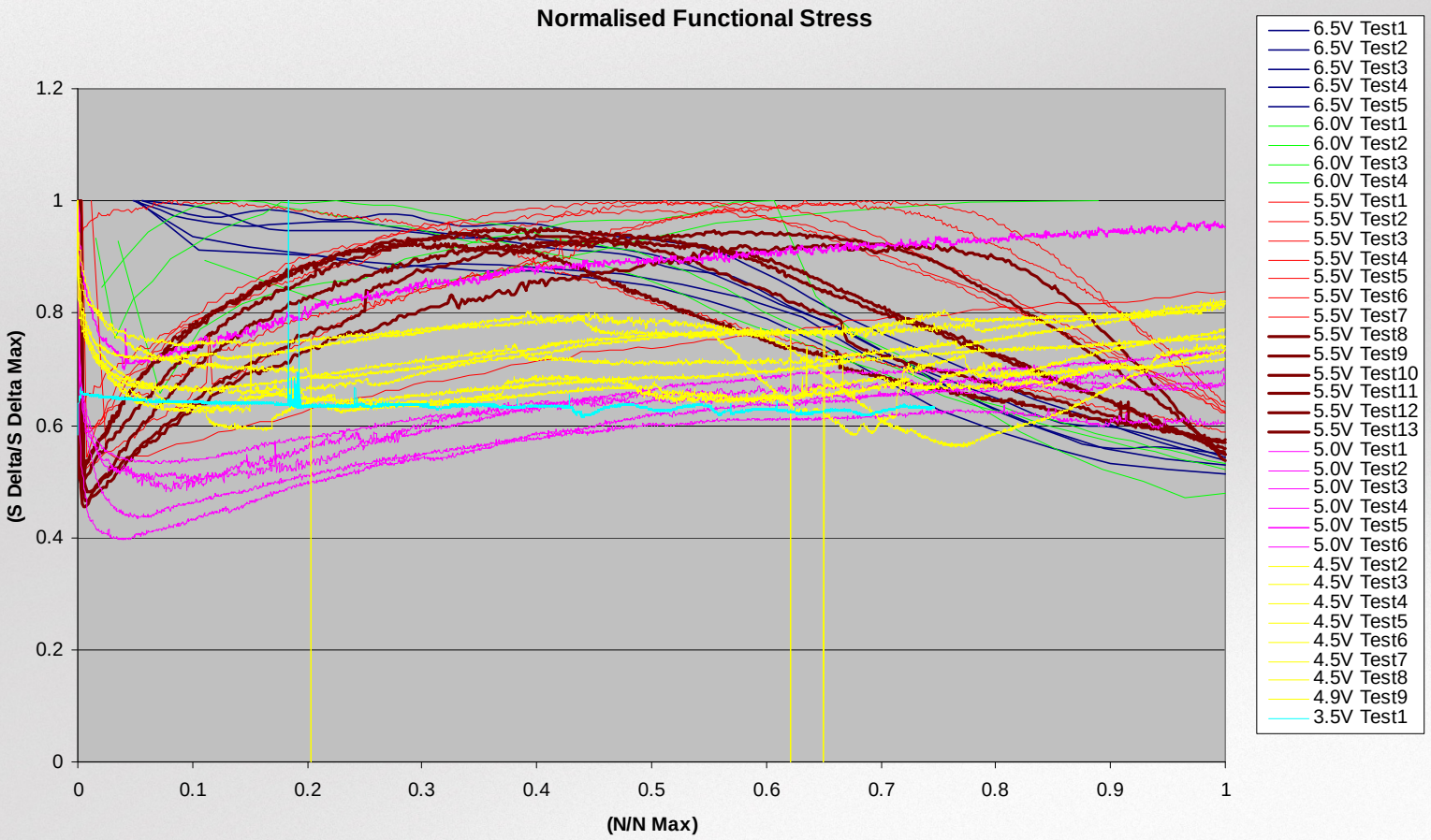




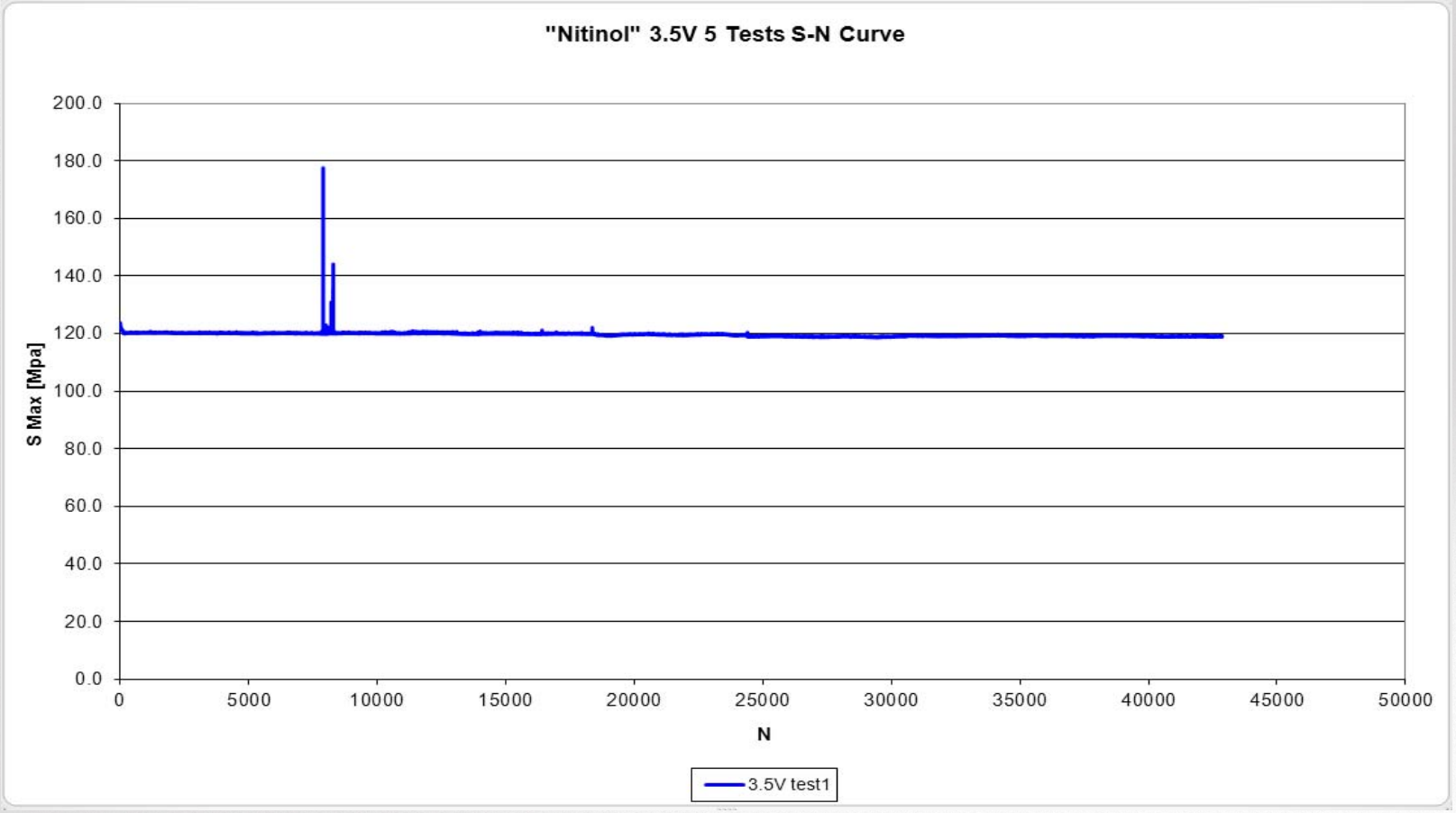
RESULTS – Normalised Charts



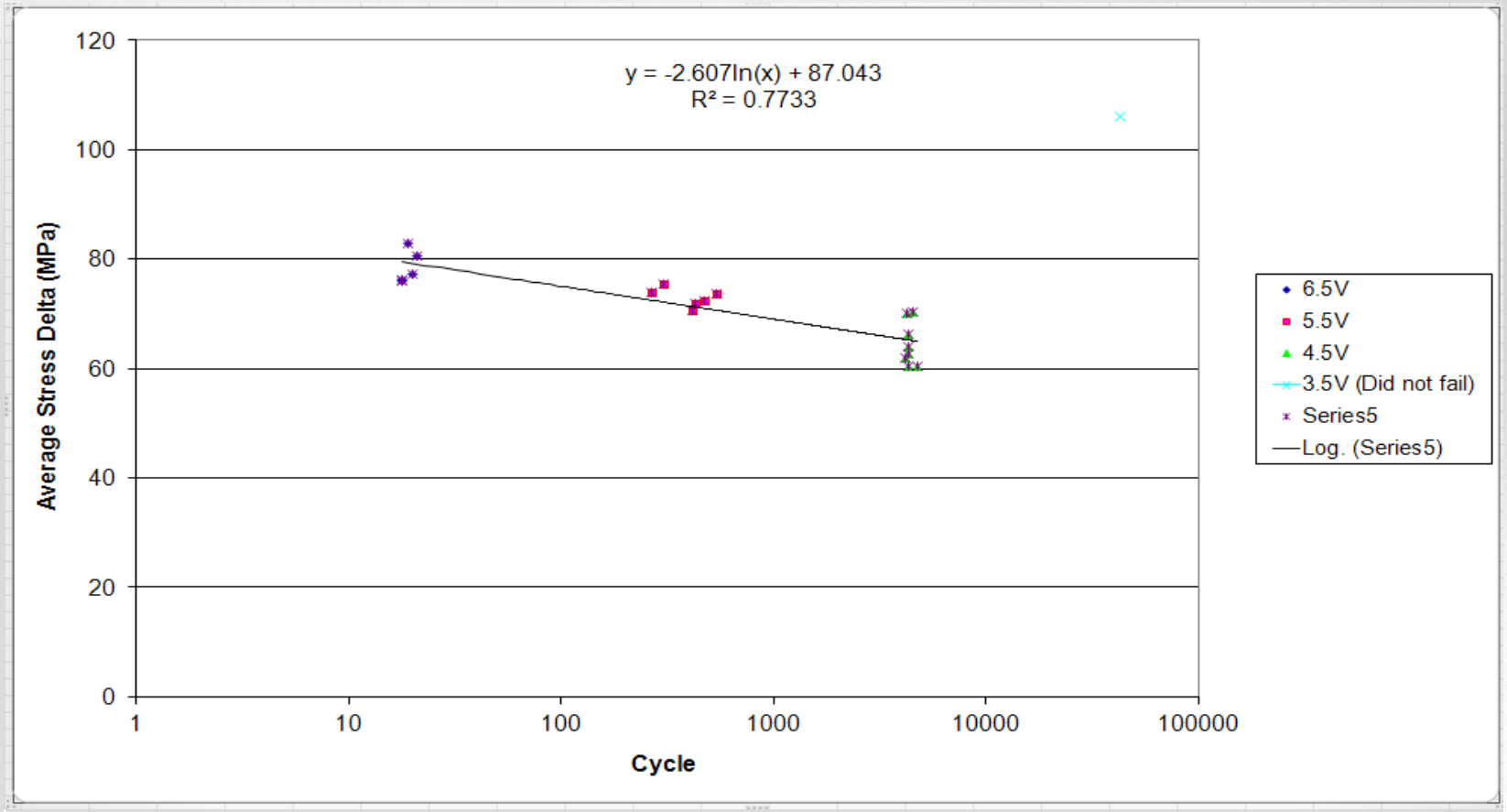
RESULTS – Normalised Charts Combined



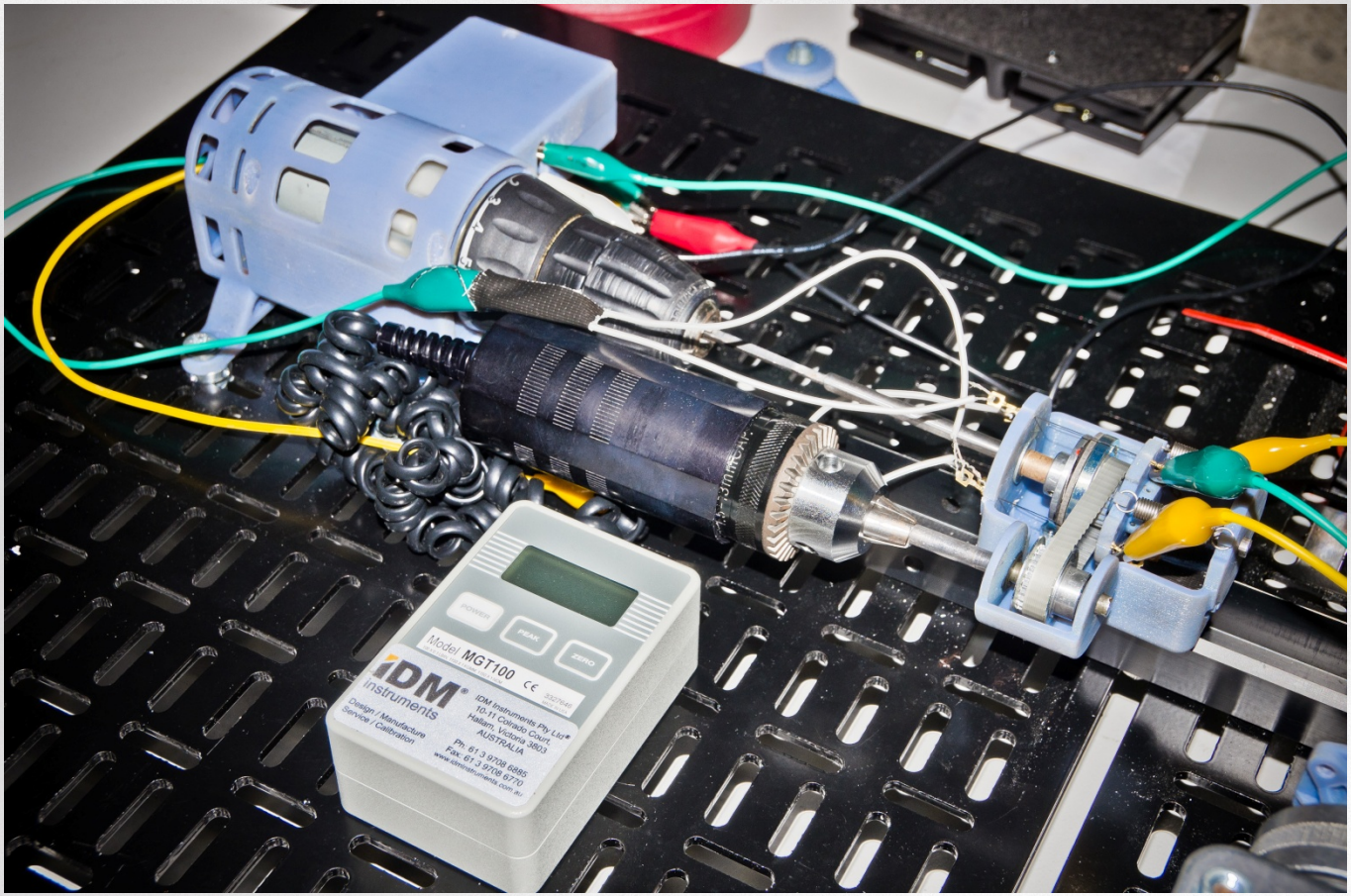
RESULTS - Discovery



RESULTS – Overall Tendency



APPLICATIONS



CONCLUSIONS & FUTURE WORK

•The voltage is inversely proportional to the life of the SMA wire.

•3.5 V seems to have an “infinite” life, but needs further testing.

•The lagging media should possess high conduction and low resistance in order to conduct the heat away from the SMA during cooling to enhance the deactivation response time and thus the frequency for high frequency applications.

•Future work includes the optimisation of the model, including the diameters of SMA, lagging paste, and shell.

•Confirm the experimental results with analytical and numerical results

•Selection of a new and improved lagging paste will be under investigation in order to enhance conductivity and lower insulation resistivity to aid in conducting the heat towards the ambient.

•The steady state heating results obtained after optimisation will act as the starting point for the cooling analysis.

REFERENCES

1. Hartl D. and Lagoudas D. C., *Aerospace Applications of Shape Memory Alloys* Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, 2007. **221**(Number 4 / 2007): p. 535-552.

2. Leary M., Schiavone F., and Subic A., *Lagging for control of shape memory alloy actuator response time*. Materials & Design, 2010. **31**(4): p. 2124-2128.

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4. Incropera F. P. and DeWitt D. P., *Fundamentals of Heat and Mass Transfer*. FIFTH EDITION ed. 2002: John Wiley & Sons, Inc.

QUESTIONS?