Characterization, Analysis and Modeling of a MEMS Based Nitinolactuator

Alkausil Tamboli
Department of Mechatronics, SRM University, Chennai-603203, India
Email: al_kouse@yahoo.com

A. Vimala Juliet
Department of I&C Engineering, SRM University, Chennai-603203, India
Email: ice.hod@srmuniv.ktr.ac.in

***Abstract*—The paper presents the modeling and simulation of a Nitinol based microactuator for evaluation of the characteristics of this microactuator. The displacement, pressure, stress and von mises stress characteristics are presented and verified using COMSOL Multiphysics 4.4.The characterization of these parameters proves to be useful in the development of the design of these smart actuators exhibiting shape memory effect. The resistivity of Nitinol is suitable for Joules Heating. Therefore microactuator in this current study is of dimensions 1000×600×200µm is characterized at different temperature during the martensitic and austenitic phase transformation.**

***Index Terms*—microactuator, shape memory effect, phase transformation, nitinol, austenitic, martensitic**

I. Introduction

Smart actuators are the need of current times due to high compatibility, robustness, large force and cost effectiveness [1]. These actuators also possess a high work output per unit volume and is used in many actuation applications. Nitinol is a prospective material for various microactuating mechanisms. These actuators find major application in microdevices including the long range of micromanipulators viz. micropumpsand valves [2].

The specifications of the Nitinol based microactuator are,

Range of motion=5% of the length
Force generated=600MPa(approximately)
Response speed=100Hz
Driving Voltage=0.5-10volts
Work output per volume=$3\times10^7\,{}^{J}/_{m^3}$

Modeling and analysis of these actuators provide an useful information for designing and developing of these actuating components in MEMS (Micro Electro Mechanical Systems) technology.

Manuscript received July 1, 2015; revised March 15, 2016.

II. Displacement Characteristics

The expansion takes place in the actuator at higher temperature as the phase transformation takes place from the martensitic phase to the austenitic phase.The growth in the actuator is given as [3].

$$\varepsilon = 1 - \exp[a^M(M_s - T) + b^M\vec{\sigma}] \quad (1)$$

a^M and b^M are stress coefficients during martensitic phase,

M_s =Phase change temperature

T=temperature at which the phase transformation occurs

$\overline{\sigma}$=equivalent stress.

In the austenite stage the growth is given as,

$$\varepsilon = \exp[a^A(A_s - T) + b^A\overline{\sigma}] \quad (2)$$

a^A and b^A are the stress coefficients in the austenitic phase

$A_s$is the phase change temperature in the antiphase. The displacement analysis are shown in Fig. 1.

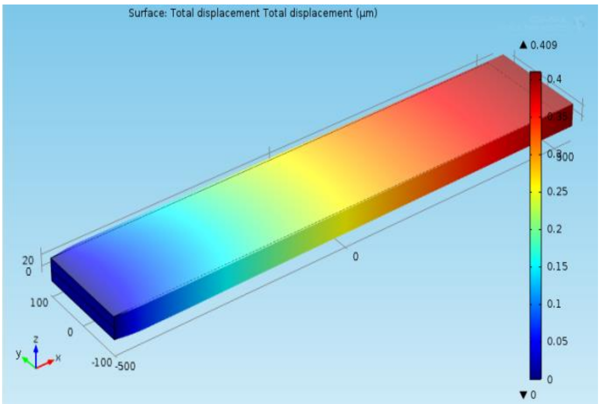

Figure 1. The displacement in the microactuator at 400K (FEM analysis)

The elongation in the microactuator increases with an increase in the temperature. In the austenitic phasegreater elongations takes place.

The displacement characteristics are demonstrated in Fig. 2

© 2016 Int. J. Mech. Eng. Rob. Res.
doi: 10.18178/ijmerr.5.3.176-179

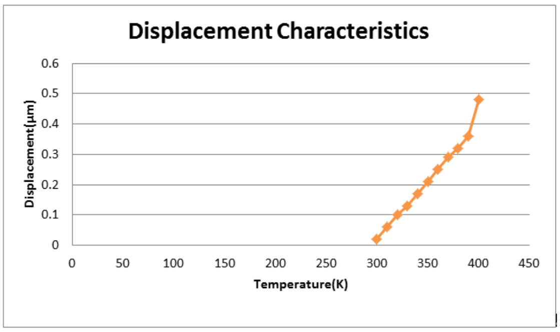

Figure 2. Displacement characteristics

III. Pressure Characterization

The Pressure in the actuator during the phase transformation is given as,

$$P = F[a(1 - \epsilon^2) - b] \quad (3)$$

F=force in the actuator,

$$a = \frac{3}{\tan^2\alpha}$$

α=angle formed during the phase transformation.

∈=strain in the actuator,

$$b = \frac{1}{\sin^2\alpha}$$

The pressure in the actuator is temperature dependent and increases with an increase in the temperature. The analysis depict the increase in the pressure along with the phase transformation. The simulation results using COMSOL Multiphysics 4.4 for the pressure across the actuator are demonstrated in the Fig. 3.

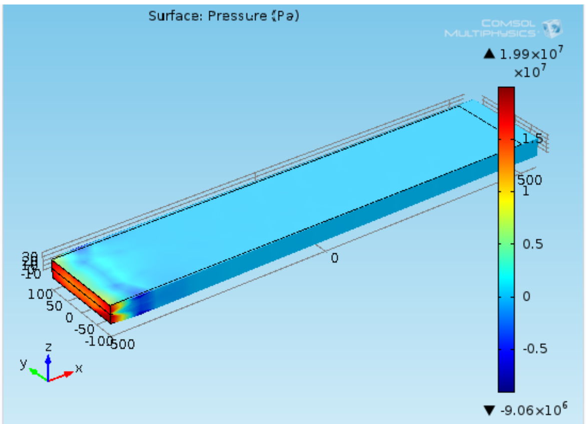

Figure 3. Pressure across the microactuator at a temperature of 350 K.

IV. Stress Characteristics

The stress of the microactuator is function of the temperature. Therefore the stress characteristics are dependent on the phase transformations that occur with the temperature in the microactuator. During the Joules heating the stress increases as the phase transformation takes place from martensite to austenite phase. Therefore the stress increases in the microactoator along with increase in temperature. The stress is analyzed for temperature varying from 300K to 400K.The stress observed at 400K was 600MPa.

The Shape Memory behavior of stress in the actuator can be described using the Clausius-Clapeyron relationship [4].

$$\frac{d\sigma}{dT} = -\frac{\rho\Delta H}{\Delta\epsilon T}$$

T =Transformation temperature,

ΔH=Latent heat,

ρ=density of Nitinol

Δ∈ =strain due to phase transformation.The stress analysis are shown in Fig. 4.

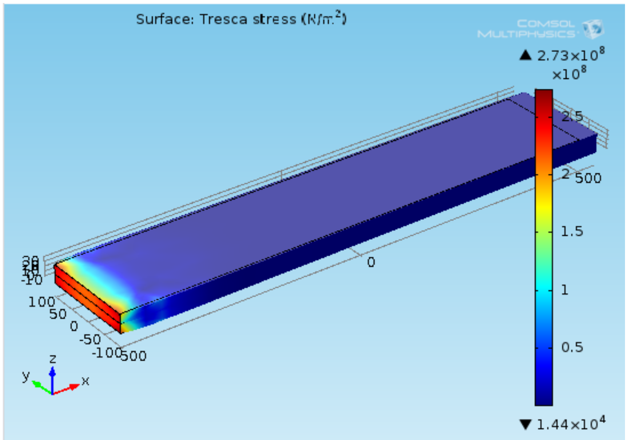

Figure 4. Simulation Analysis(350 K)

Stress Tensor analysis(X-component) are exhibited in Fig. 5.

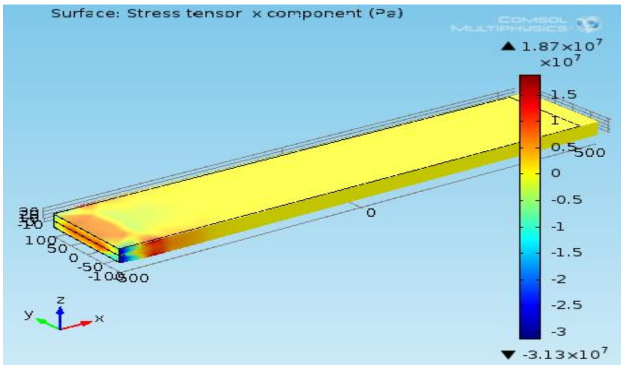

Figure 5. Stress Tensor(X-component)

Stress Tensor analysis(Y-component) in Fig. 6.

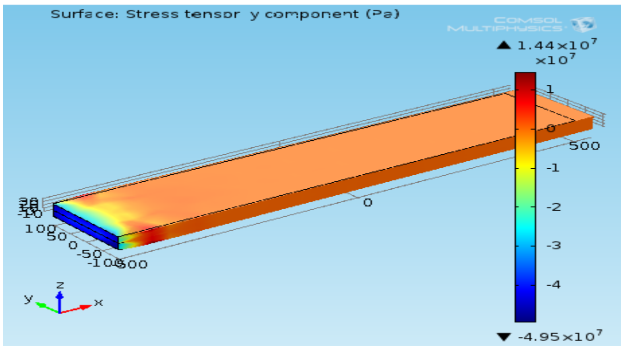

Figure 6. Stress tensor (Y-component). Stress Tensor(Z-component) is shown in Fig. 7

© 2016 Int. J. Mech. Eng. Rob. Res.

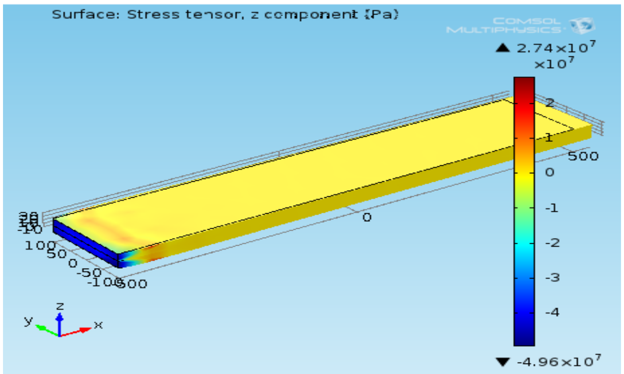

Figure 7. Stress tensor analysis(Z-component)

V. Strain Analysis

The strain model during the Joules Heating can be given as [5],

$$\in = a_e(T - T_o)$$

$\in$=strain in the actuator,

a_e=coefficient of thermal expansion,

T=Phase Transformation temperature,

T_O=Ambient temperature.The strain analysis prove to be useful in the design of actuator for various micromanipulation application [6]. The strain analysis are demonstrated in Fig. 8.

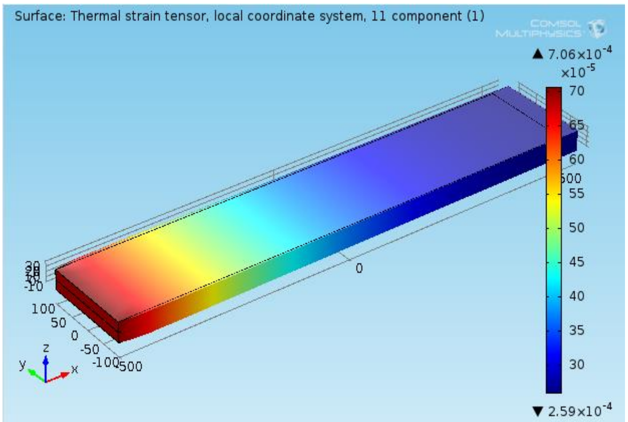

Figure 8. Strain Analysis across the actuator. (400 K).

The strain Tensor along the X-component is shown in Fig. 9.

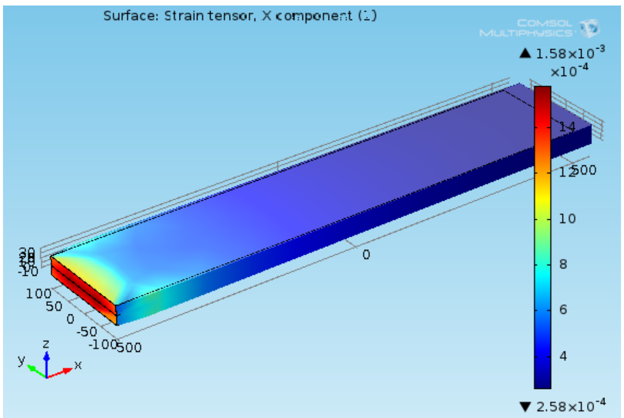

Figure 9. Strain tensor analysis (X-component)

Strain Tensor (Y-component) is demonstrated in Fig. 10.

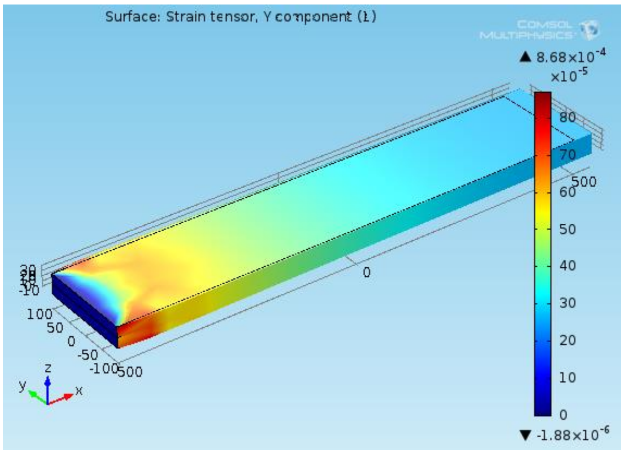

Figure 10. Strain tensor analysis (Y-component)

The strain tensor analysis (Z-component) are shown in Fig. 11.

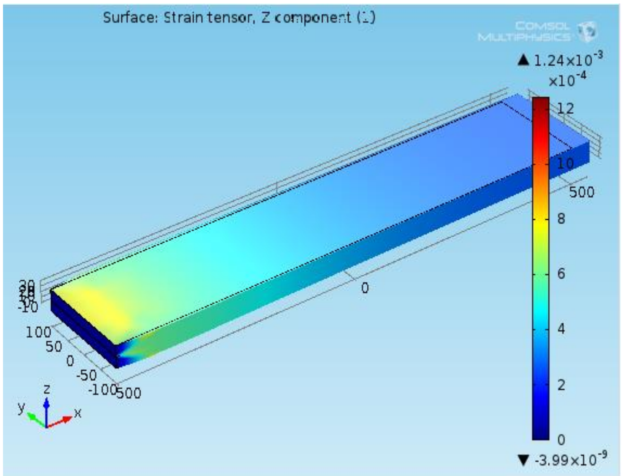

Figure 11. Strain tensor analysis (Z-component)

The Pressure characteristics with the temperature variations are demonstrated in Fig. 12.

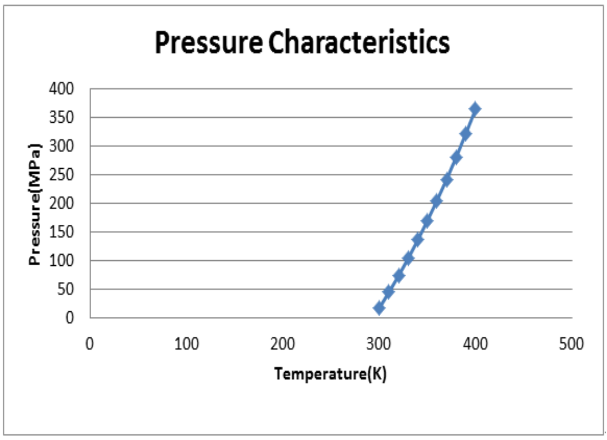

Figure 12. Pressure characteristics at temperature variations for the micro actuator

The Stress Characteristics are shown in Fig. 13.

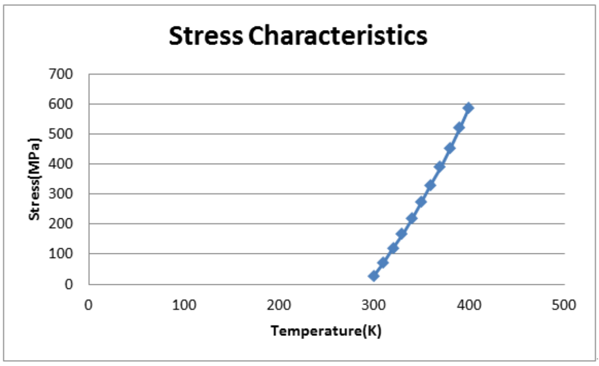

Figure 13. The stress charactersistic curve under the phase transformation with increasing temperature

VI. VONMISESSTRESS CHARACTERSISTICS

The analysis of the Von mises stress proves to be useful for the determination of the yield of the actuator when subjected to complex loading conditions. At higher temperatures the phase transformation brings a variation in the Von mises stress across the actuator. The simulation results for the Von mises stress are demonstrated in Fig. 14.

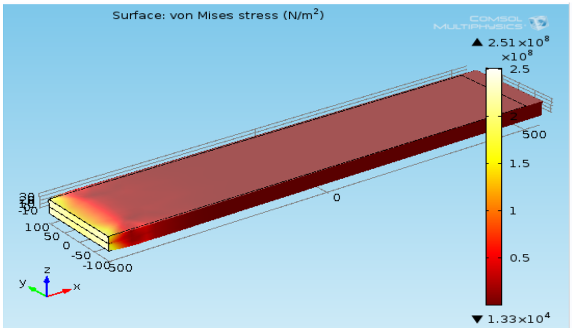

Figure 14. Simulation results of Von mises stress at 350 K

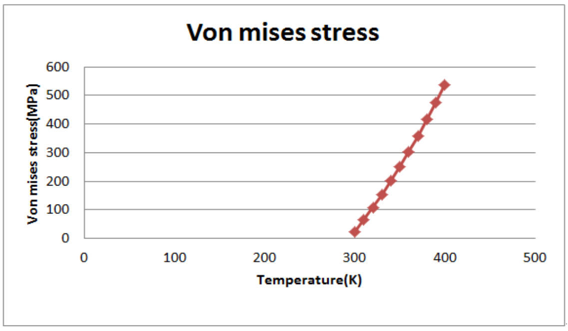

Figure 15. Vonmises stress characteristics in the microactuator

The Von mises stress with the variations in temperature are shown in Fig. 15

VII. SUMMARY

The characteristics of the Nitinolmicroactuator were precisely studied and modeling of these characteristics was verified using COMSOL Multiphysics 4.4. The characteristics curves were plotted for these parameters with variances in temperature. The dependence of these characteristics on the shape memory behavior during the phase transformation is demonstrated using FEM analysis on this cantilever microactuator and the mathematic model was proposed for these parameters. The characteristics obtained indicate the effectiveness of the Nitinol in the field of microactuation.

REFERENCES

[1] W. L. Bernard, "Thin film shape memory alloy actuated micropump," *Journal of Microelectro Mechanical Systems*, vol. 7, no. 2, pp. 245-251, 1998.

[2] H. Gradin, "SMA microvalves for very large flow control manufactured using wafer level eutectic bonding," *IEEE Transactions*, 2011.

[3] Y. Yang, "Design of a new SMA actuator," in *Proc. 2nd IEEE Conference on Nanoelectronics*, 2008.

[4] Y. J. Fu, "TiNi shape memory alloy thin films for microactuator applications," *Advanced Materials for Micro-and Nano-Systems*, 2003.

[5] L. W. Li, "Applicationsof MEMS actuators in Micro/Nano manipulator robots," in *Proc. 2nd International Conference on Computer Engineering and Technology*, 2010.

[6] Y. Fu, "TiNi thin films for MEMS applications: Areview," *Sensors and Actuators*, vol. 112, 2004.

Alkausil Tamboli. He was born in Maharashtra in 1996.Currently studying B.techin Mechatronics, SRM University, Chennai (3rd year). He is an associate research fellow in National MEMS Design Centre, Chennai. His research areas include Shape memory alloys bsed microactuators, hybrid microactuators, microvalves and micropumps.

Vimala Juliet. She has obtained her PhD in Instrumentation Engineering in 2005, Anna University, Chennai. She is currently the Head of Department, I& C Engineering, SRM University, India. She has authored several research papers and is the faculty advisor at NPDMASS. Her research areas include Fuzzy logic systems, MEMS and Control Systems.

© 2016 Int. J. Mech. Eng. Rob. Res.