

## 専門分野「計算固体力学(Computational Solid Mechanics)」

材料と構造のマルチフィールド・マルチスケール力学問題を対象として、有限要素法などの数値シミュレーション手法の開発と工業設計解析および先端テクノロジーへの応用に関する研究を行ってきた。

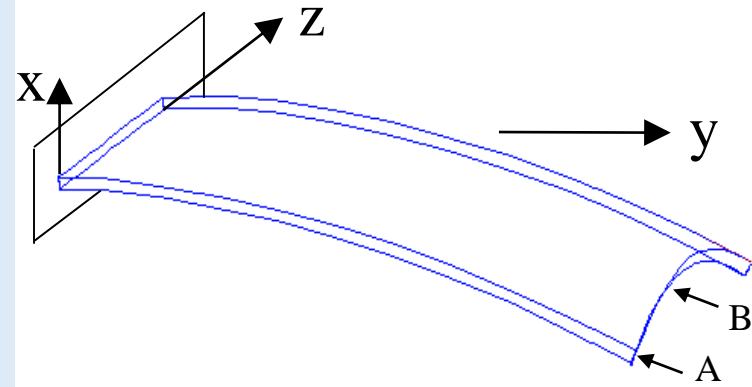
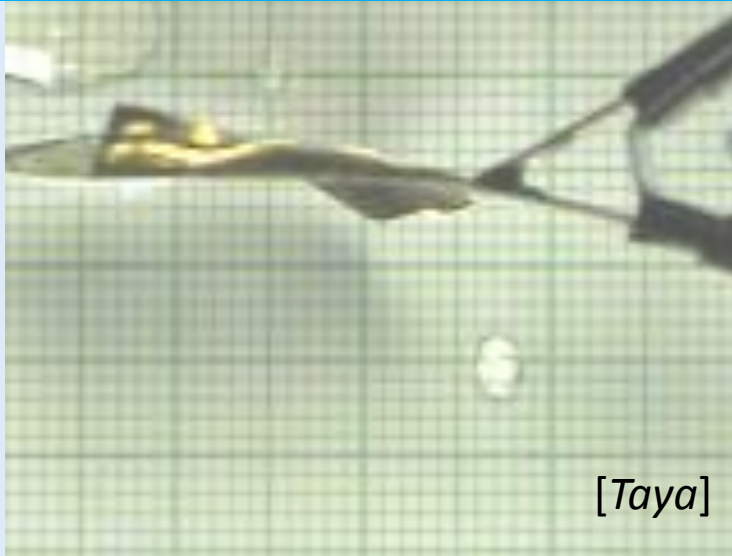
(1)計算構造工学:非線形・マルチフィールド構造解析法の開発

(2)計算損傷力学:材料損傷・構造寿命のメソ力学評価法の開発

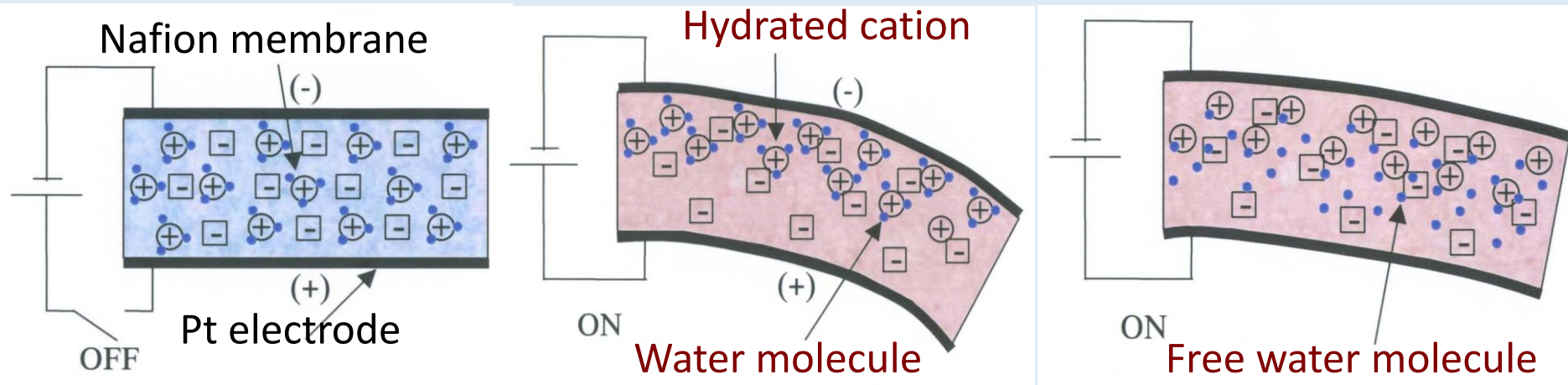
(3)計算機能材料工学:先端機能材料とアクチュエータ/センサの計算モデリング

- ①形状記憶合金素子の超弾性・形状記憶効果
- ②強磁性形状記憶合金アクチュエータの磁場・超弾性挙動
- ③多孔質形状記憶合金素子の動的超弾性挙動
- ④イオン導電性高分子(Nafion、Flemion)金属複合材の電気化学・力学挙動
- ⑤導電性高分子(Polypyrrol、Polyaniline)の電気化学・多孔質弾性挙動

イオン導電性高分子・金属複合材の電気・化学・力学的挙動の有限要素モデリング  
 [47.都井・姜2004]



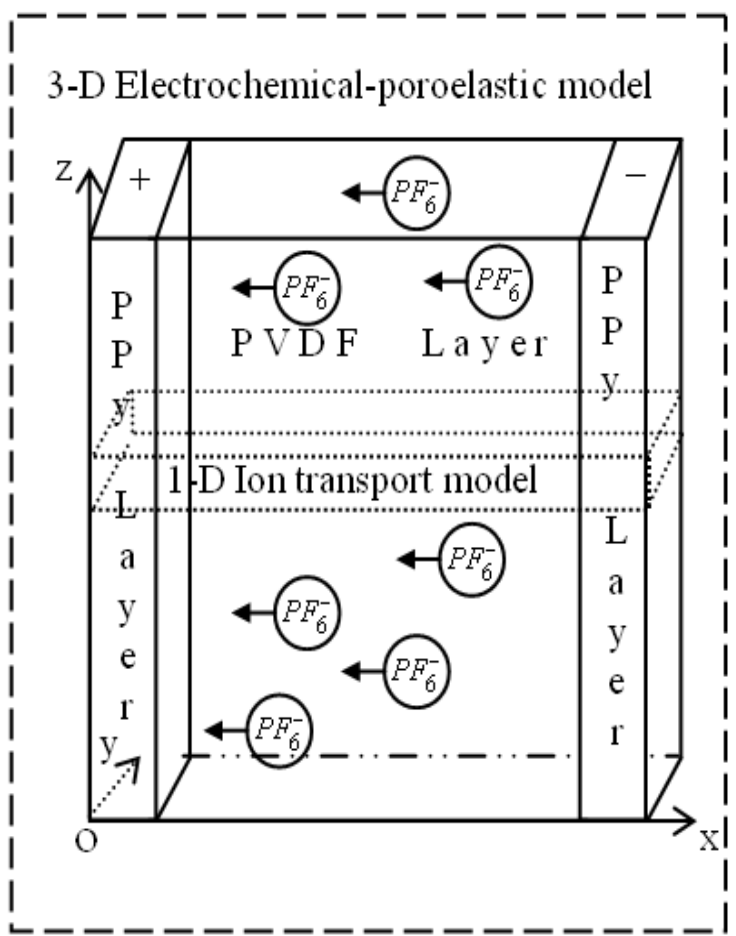
Calculated deformation



No Voltage

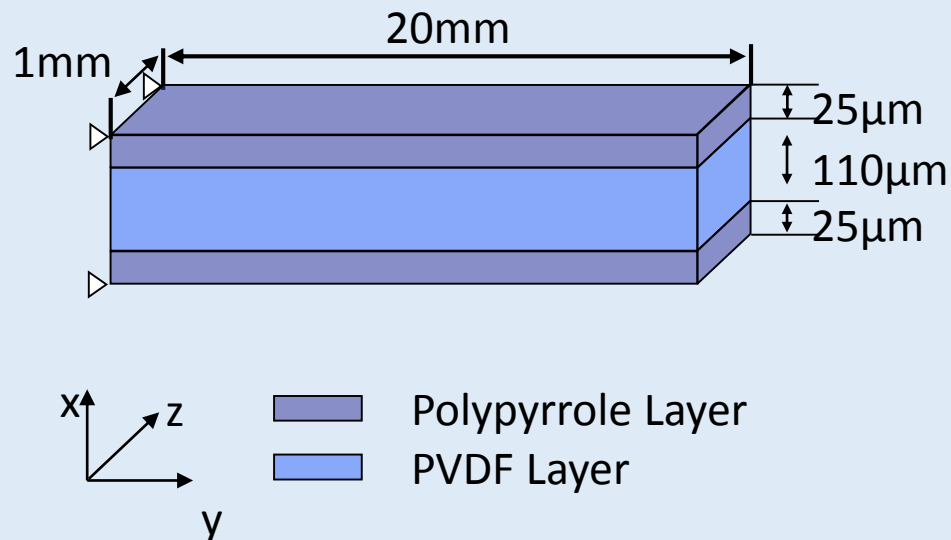
(1) **Forward motion** 0 – 0.1sec  
 (fast bending towards anode)  
 electroosmosis of hydrated ion

(2) **Backward motion** 0.1-10sec  
 (slow relaxation process)  
 self-diffusion of free water molecules

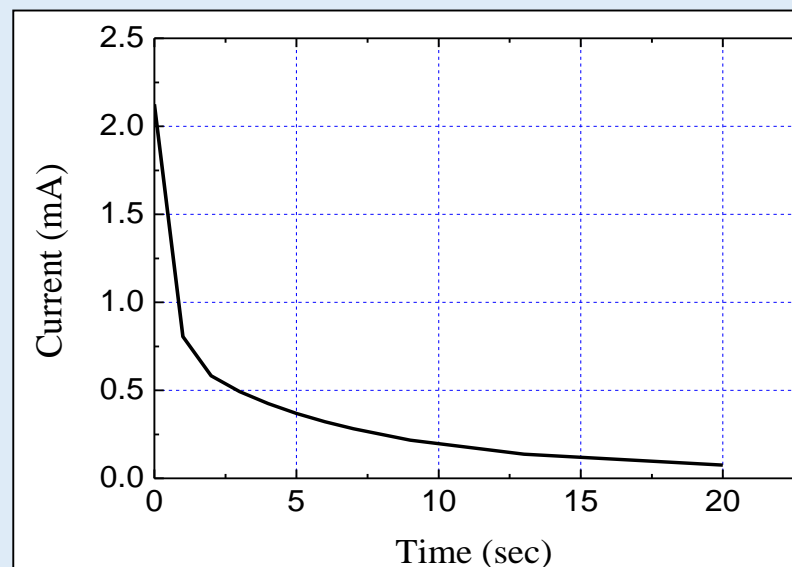


PVDF : ポリフッ化ビニリデン  
 $PF_6^-$  : ヘキサフルオロリン酸

(a) Schematic diagram [Alici, 2006]

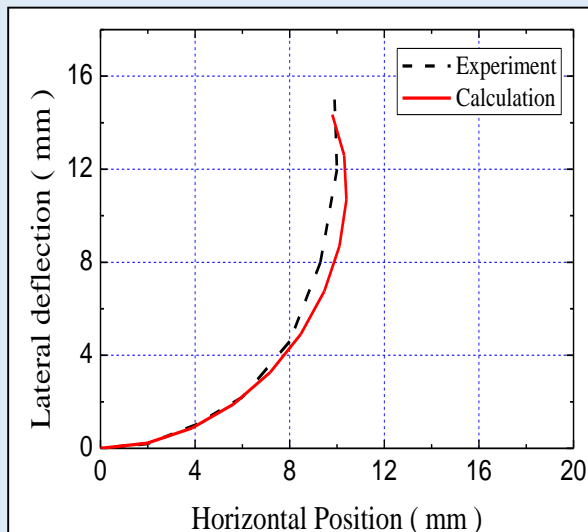


(b) Dimensions of PPy/PVDF/PPy actuator

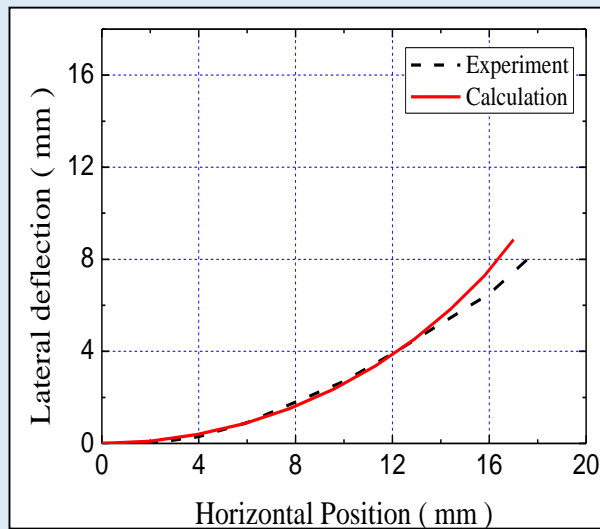


(c) Current input

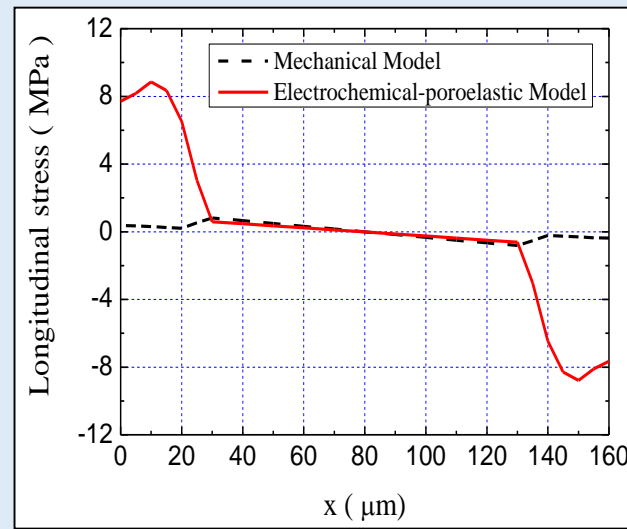
# 導電性高分子膜の電気化学・多孔質弾性曲げ挙動の計算モデリング [49.都井・鄭2008]



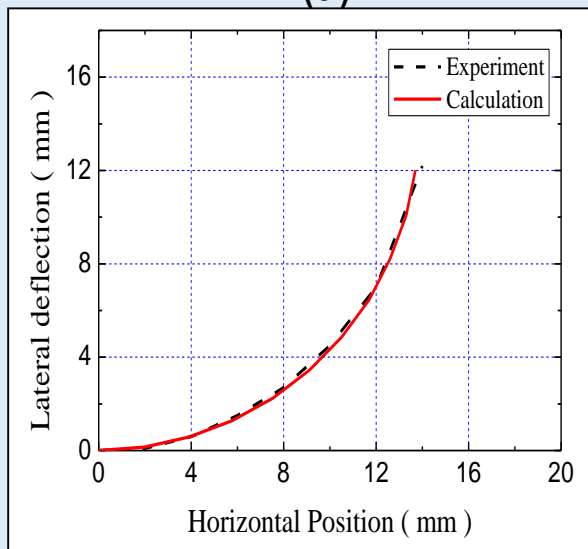
(a) 1V



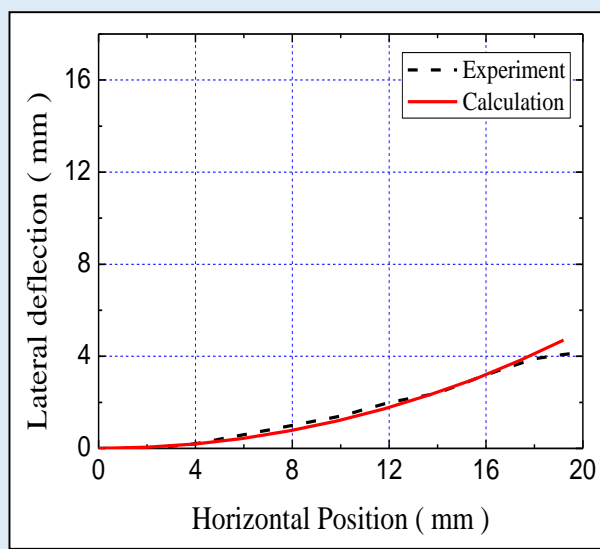
(c) 0.5V



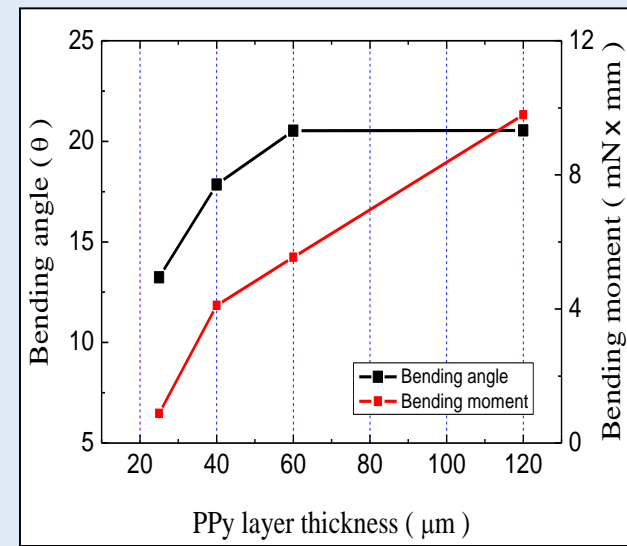
(e) Stress distribution (1V at 1.5sec)



(b) 0.75V



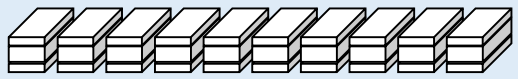
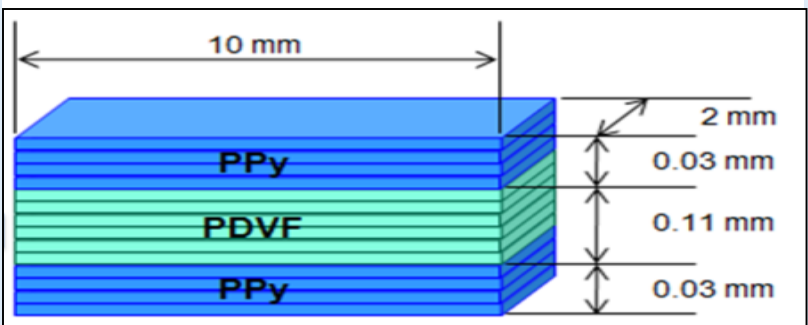
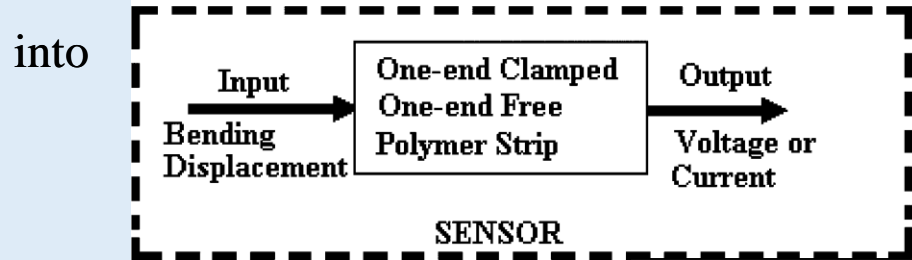
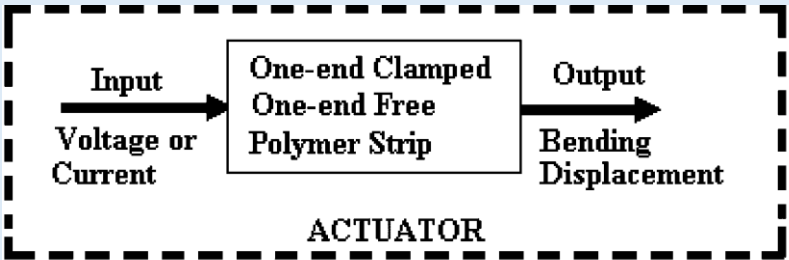
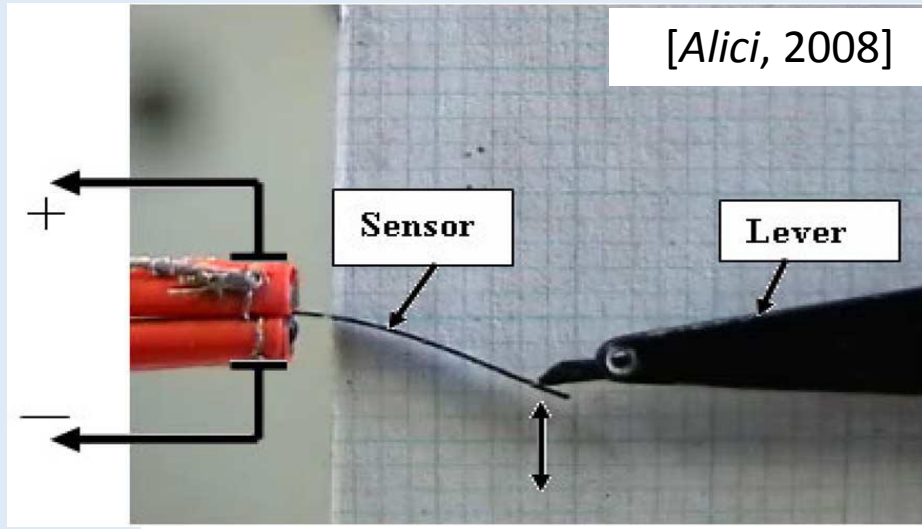
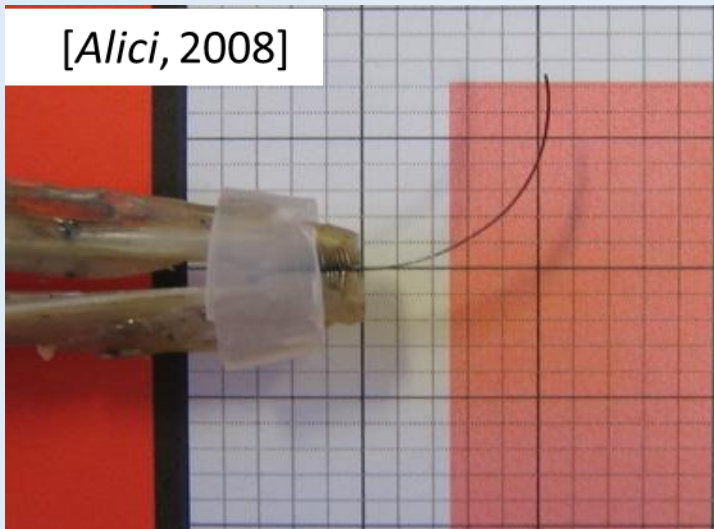
(d) 0.25V



(f) Effect of PPy layer thickness

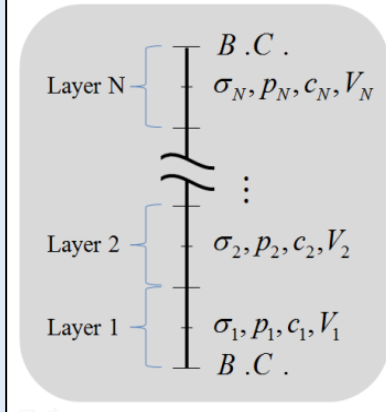
Calculated and experimental results [Alici, 2006]

# ポリピロールを用いた力学センサの計算モデリング① [50.柳・都井2014]



layered Timoshenko beam elements

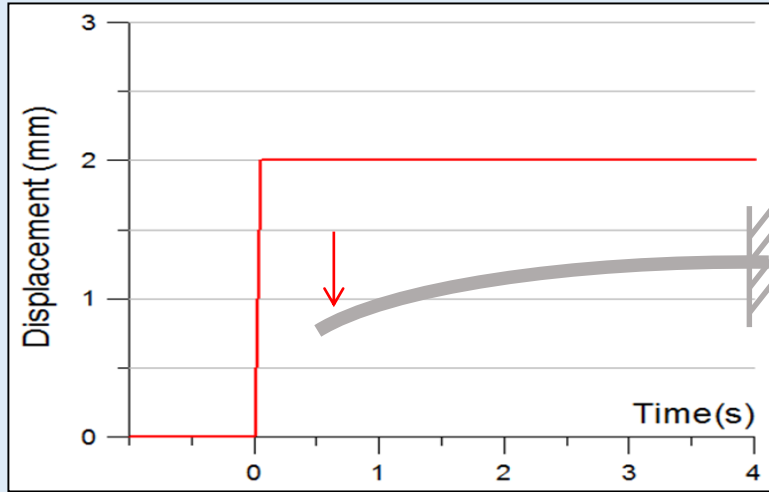
- $V_n$  : Electric potential at  $n_{th}$  layer
- $\sigma_n$  : Solid stress at  $n_{th}$  layer
- $p_n$  : Fluid pressure at  $n_{th}$  layer
- $c_n$  : Ion concentration at  $n_{th}$  layer



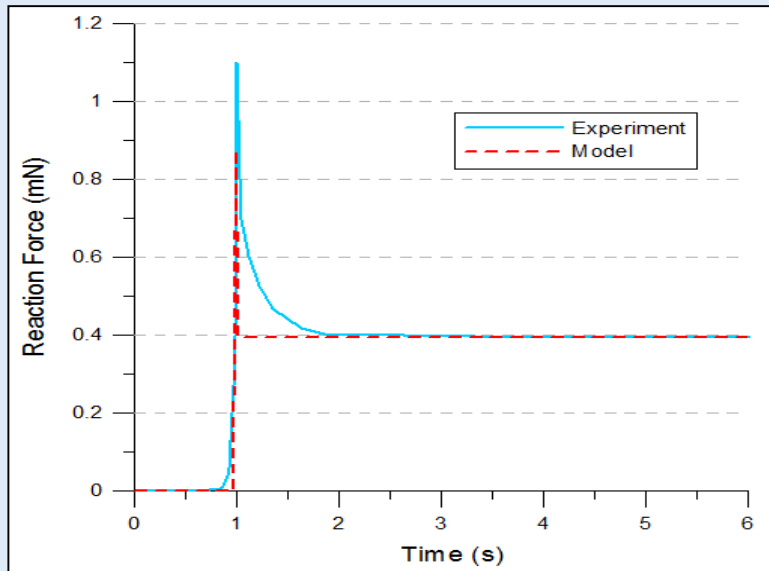
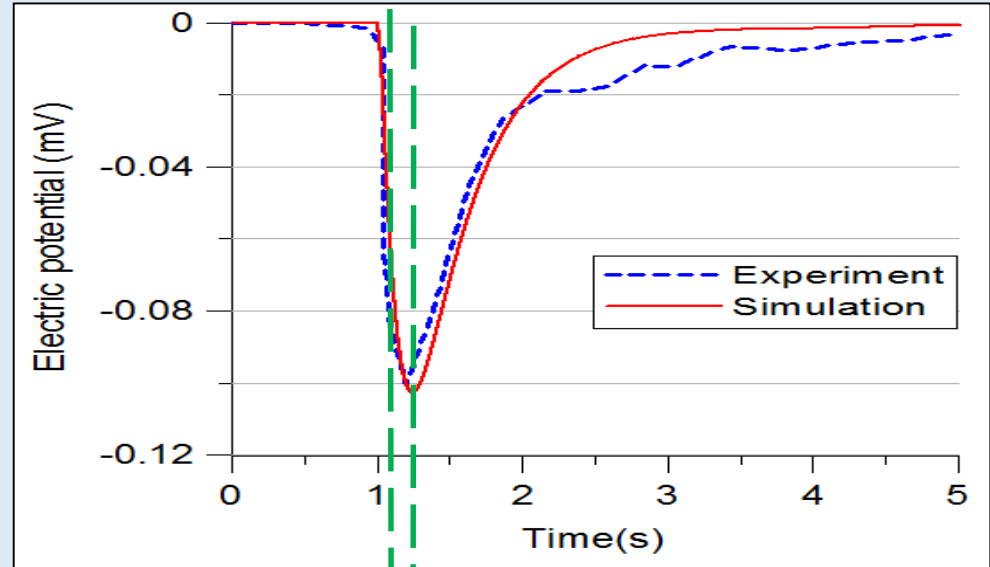
FEM

FDM

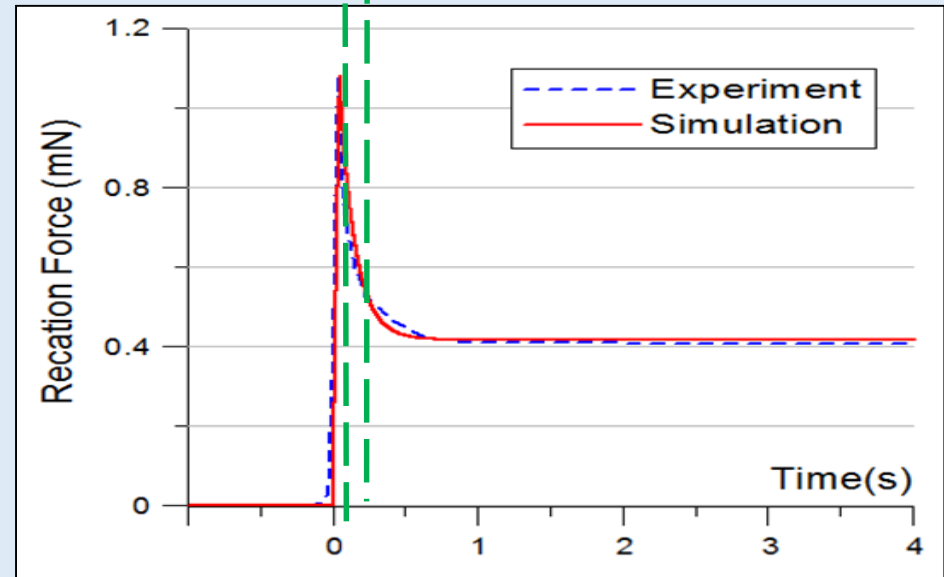
# ポリピロールを用いた力学センサの計算モデリング② [50.柳・都井2014]



Tip-displacement history



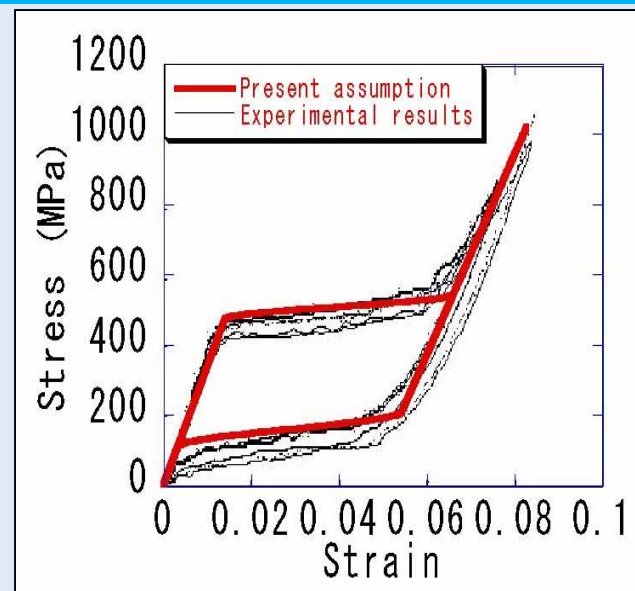
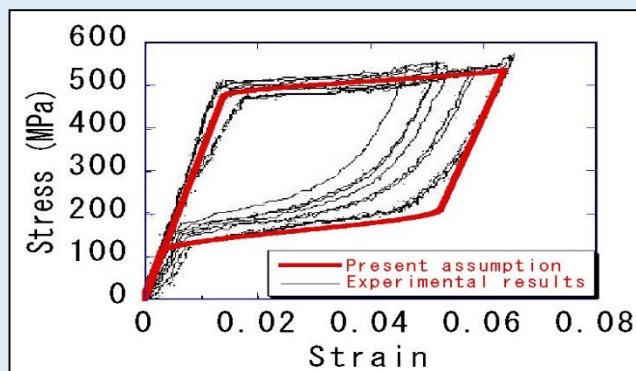
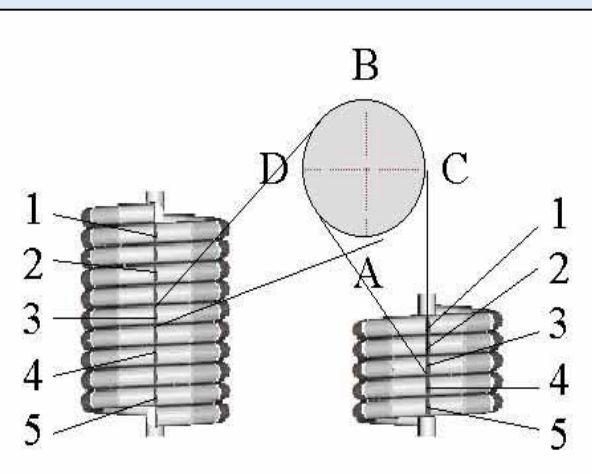
Reaction force history (black-box model)  
[Alici, 2008]



Time-history of reaction force and  
electric potential [Alici, 2008]



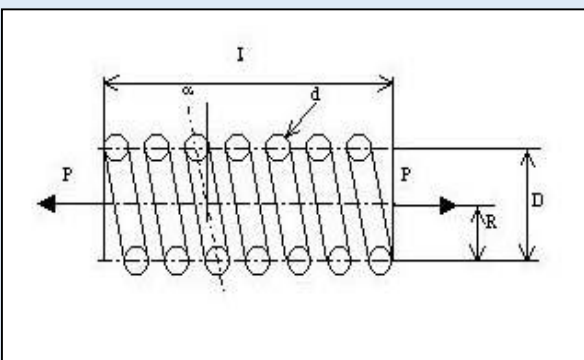
# 形状記憶合金コイルばねの超弾性挙動の有限要素解析 [51.都井・李宗賓・田谷・松永2002]



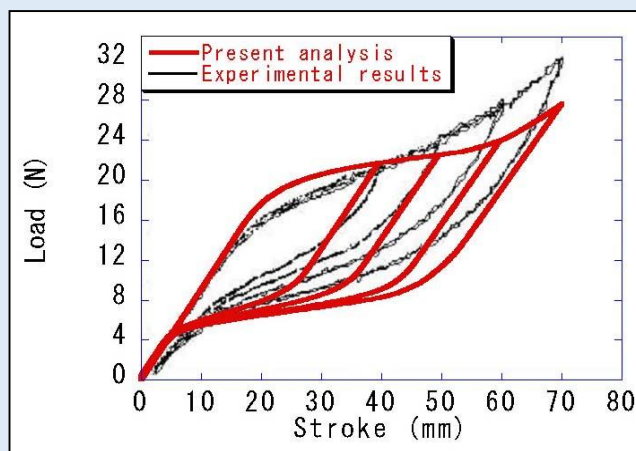
(a) short stroke

(b) long stroke

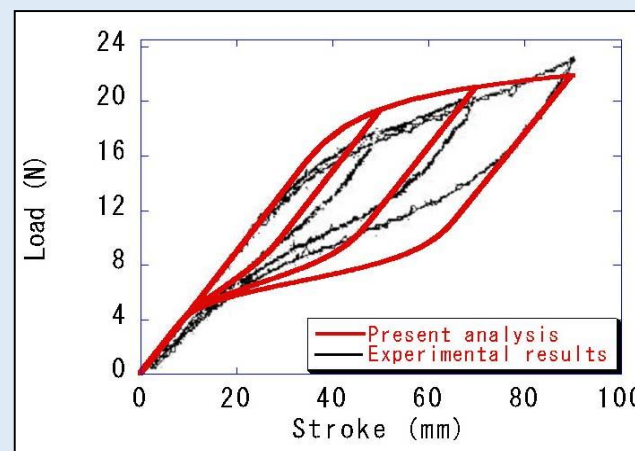
Assumed and experimental stress-strain curves [Taya]



SMA helical springs



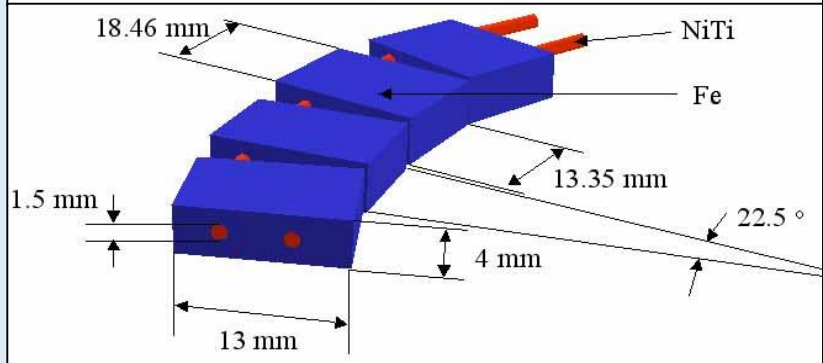
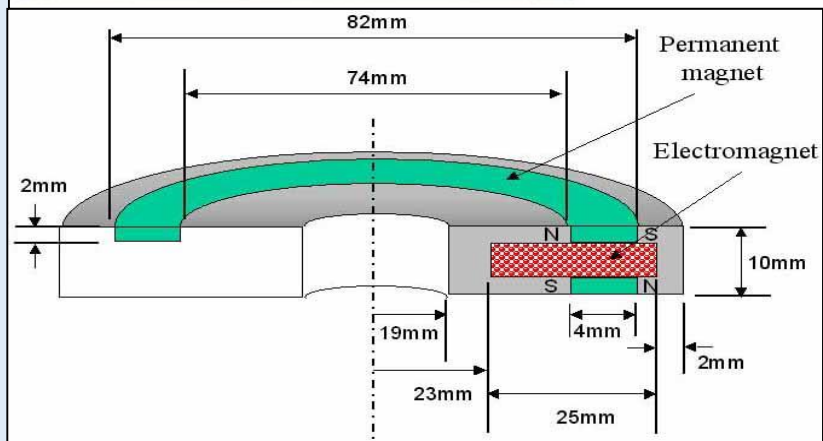
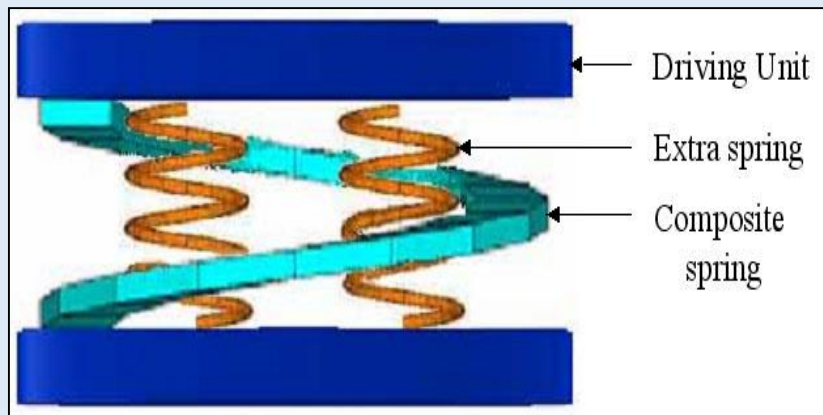
(a) 5 turns



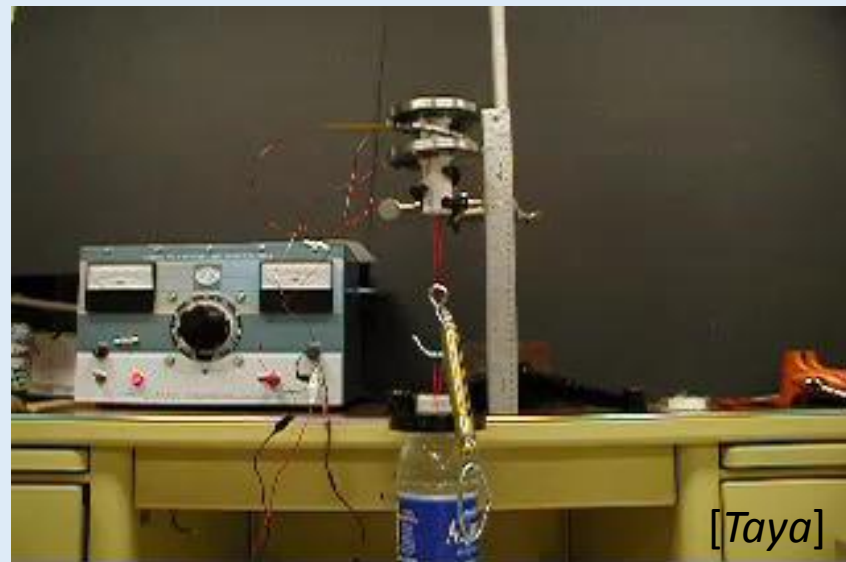
(b) 10 turns

Calculated and experimental load-stroke curves [Taya]

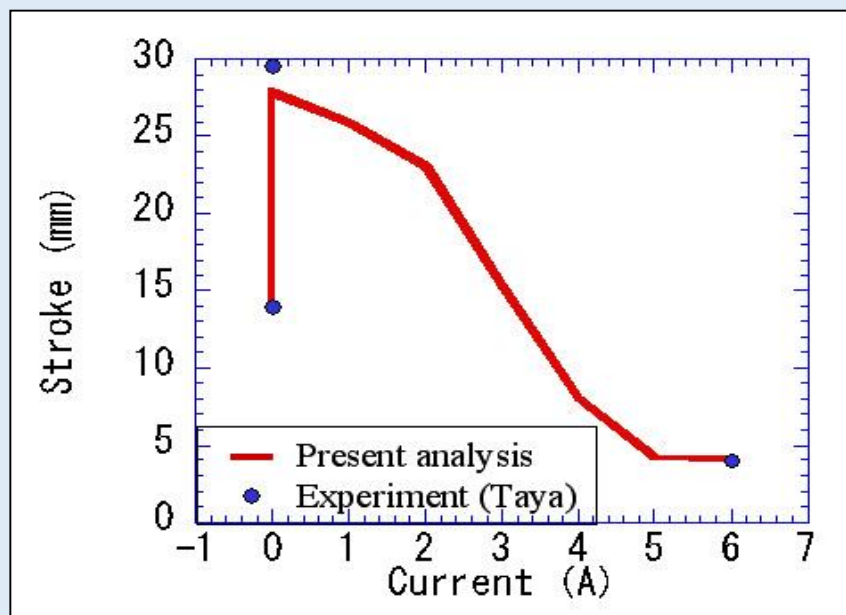
# 磁気力により制御される形状記憶合金コイルばねアクチュエータの磁場・超弾性解析 [52.都井・李宗賓・田谷2006]



SMA composite spring actuator [Taya]



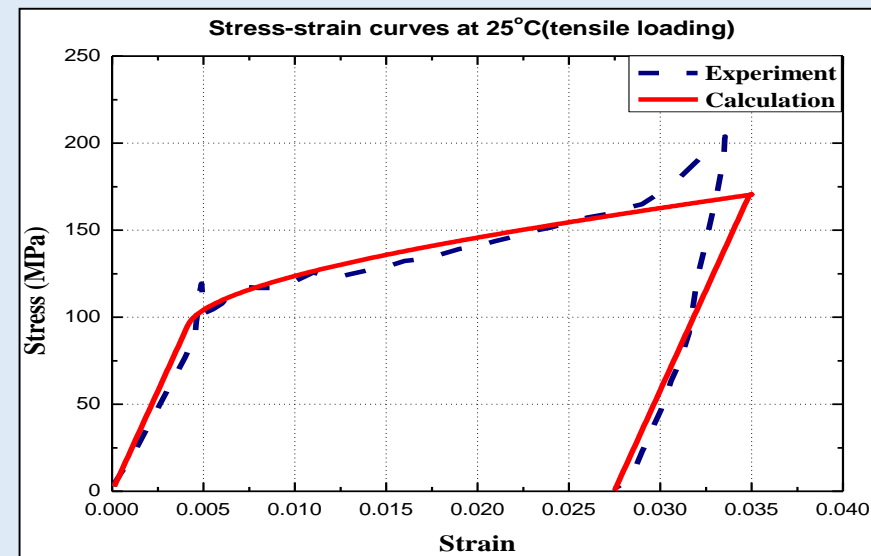
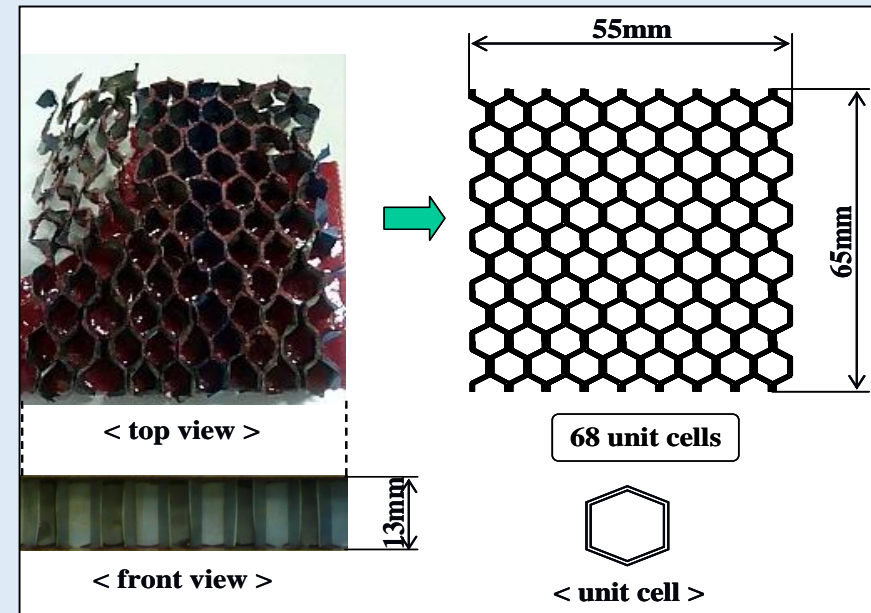
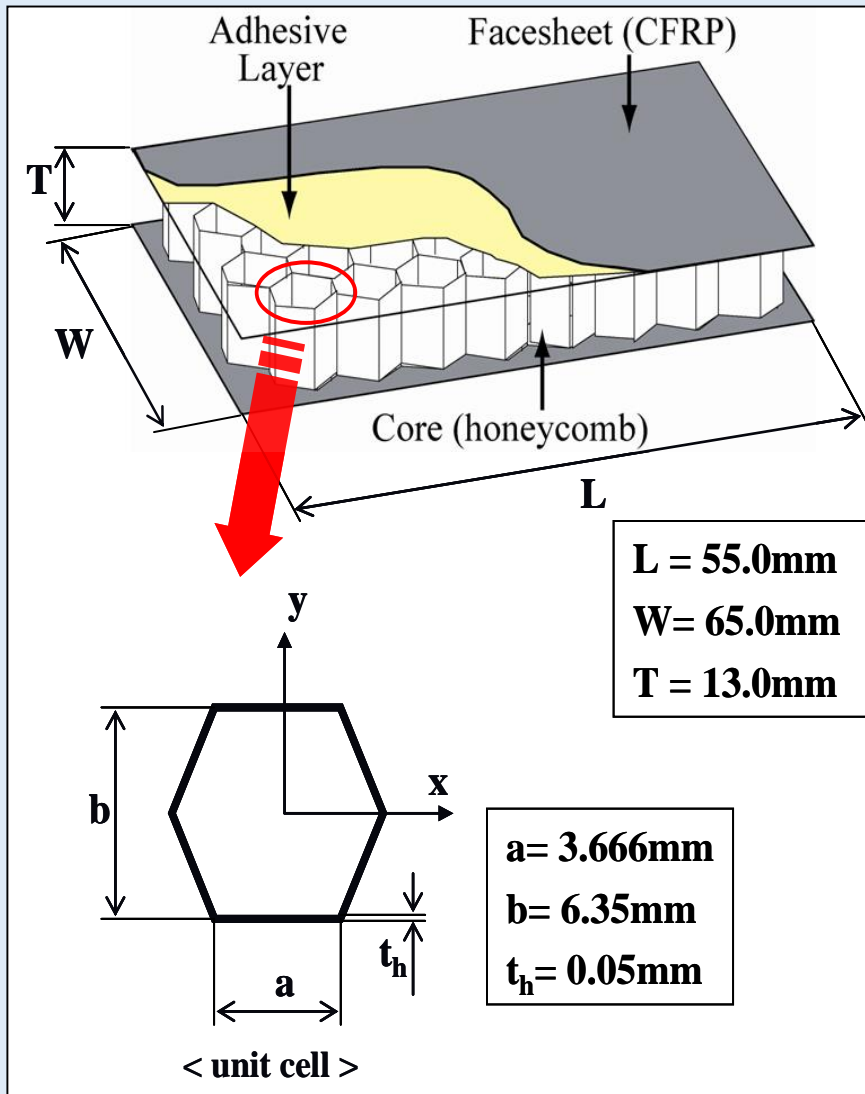
[Taya]



Current-displacement curve for SMA composite spring actuator



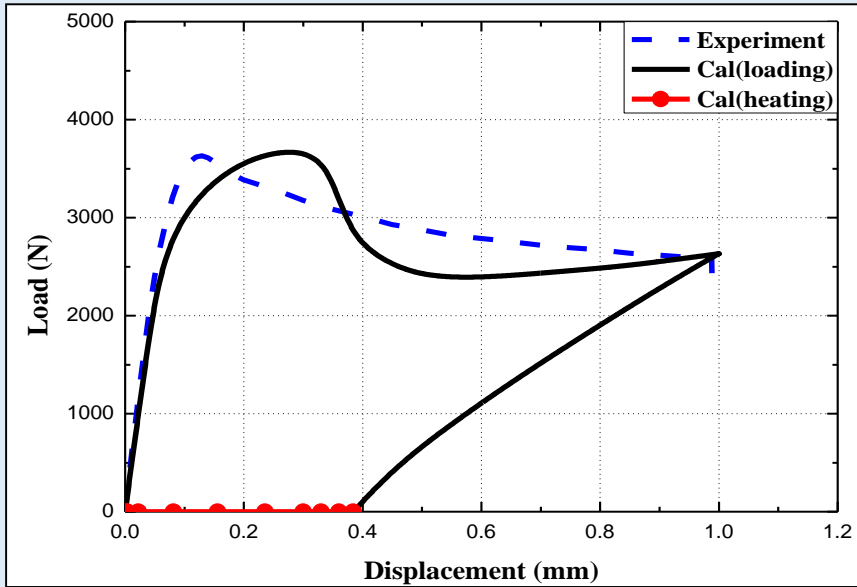
# 形状記憶合金素子の形状記憶効果に関する有限要素解析① [53.崔・都井・水口・岡部2009]



SMA honeycomb sandwich panel [Okabe, 2007]

[Okabe, 2007]

# 形状記憶合金素子の形状記憶効果に関する有限要素解析② [53.崔・都井・水口・岡部2009]



[Okabe, 2007]



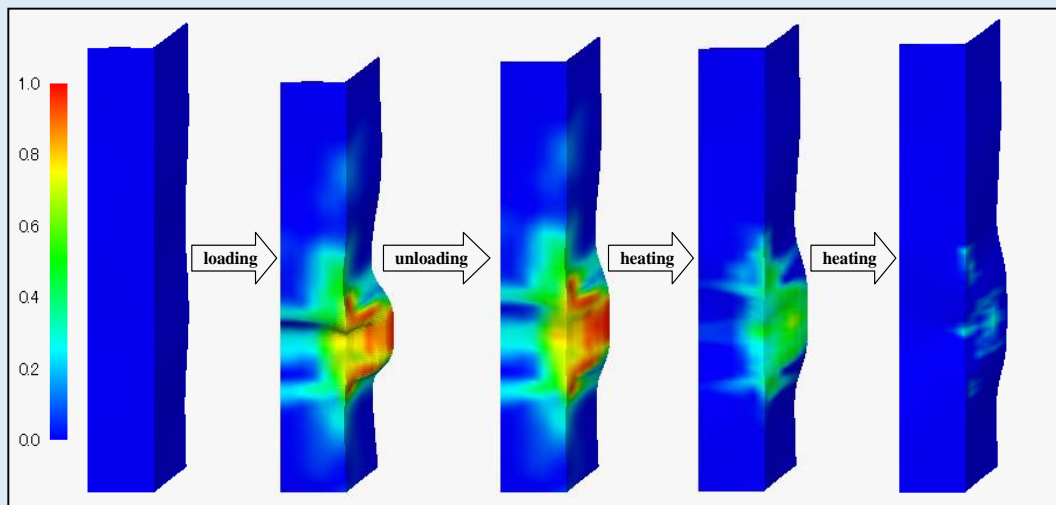
(a) Initial shape ( $F=0\text{N}$ ,  $T=25^\circ\text{C}$ )



(b) After loading ( $F=2582\text{N}$ ,  $T=25^\circ\text{C}$ )

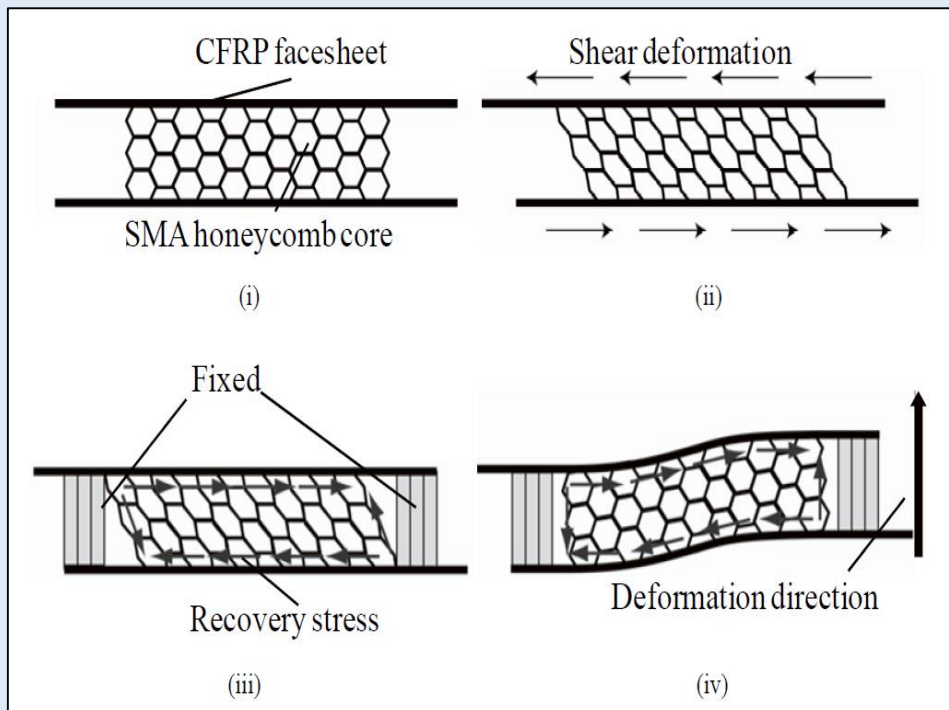


(c) After unloading and heating ( $F=0\text{N}$ ,  $T=80^\circ\text{C}$ )  
Shape memory effect [Okabe, 2007]

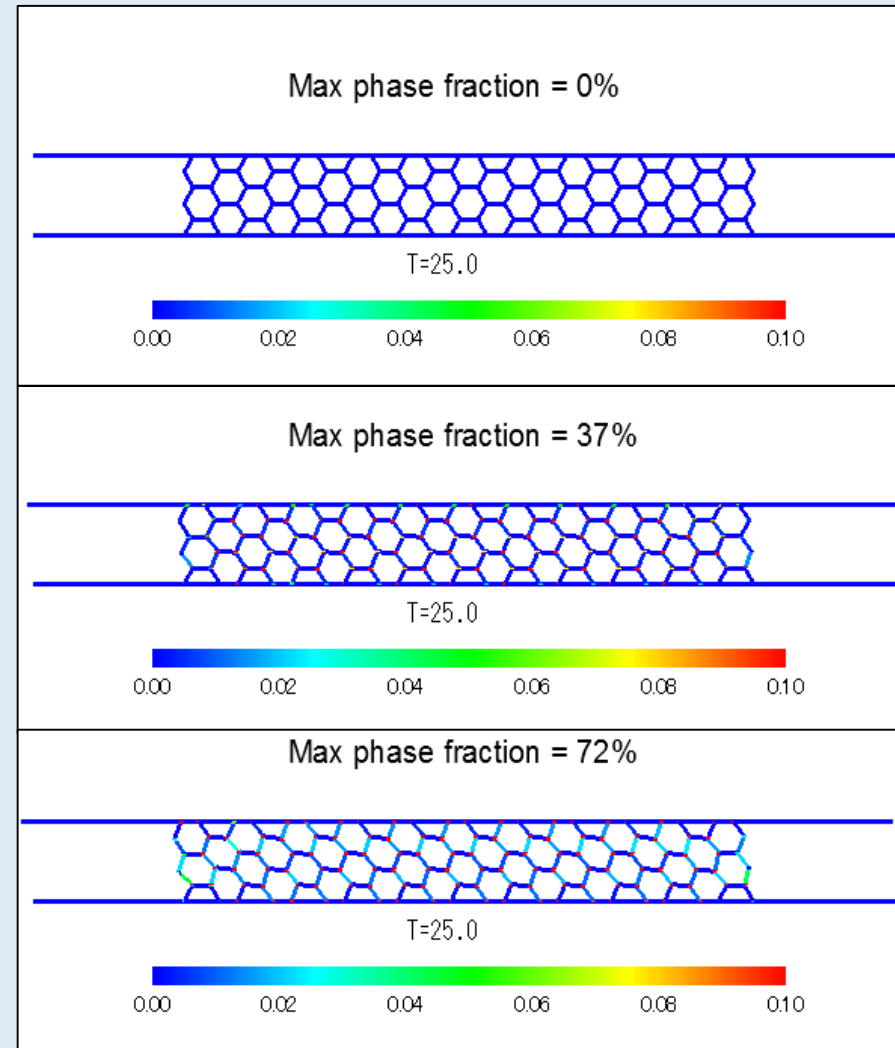


Finite element analysis of SMA honeycomb sandwich panel

# 形状記憶合金を用いたハニカムアクチュエータの有限要素解析① [54.何・都井2013]

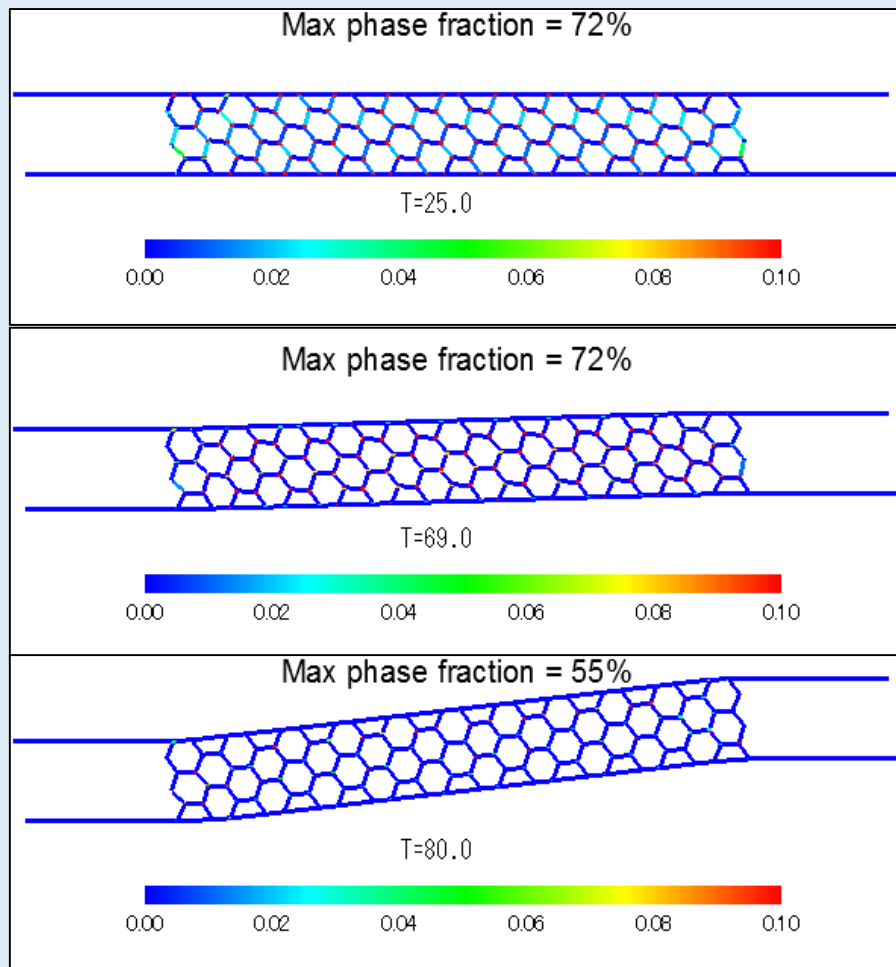


SMA honeycomb core actuator [Okabe, 2011]

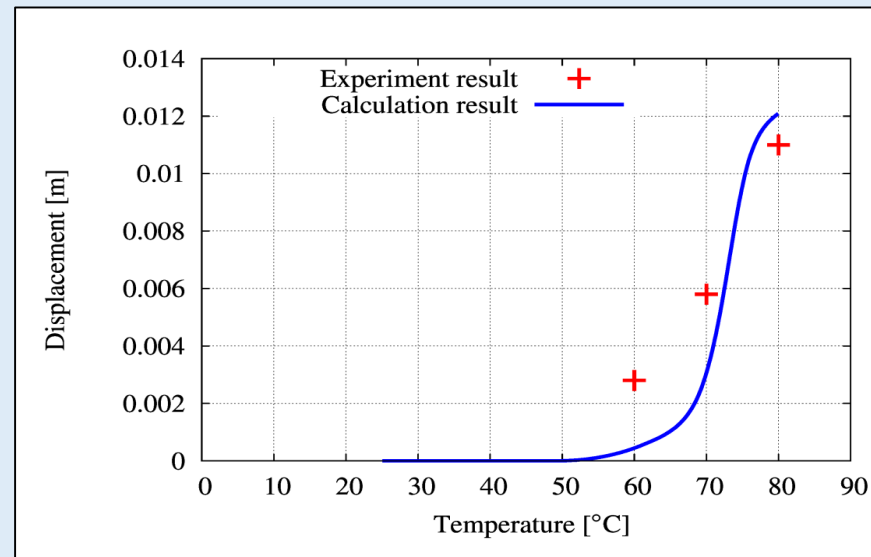


Process one: shear forced deformation

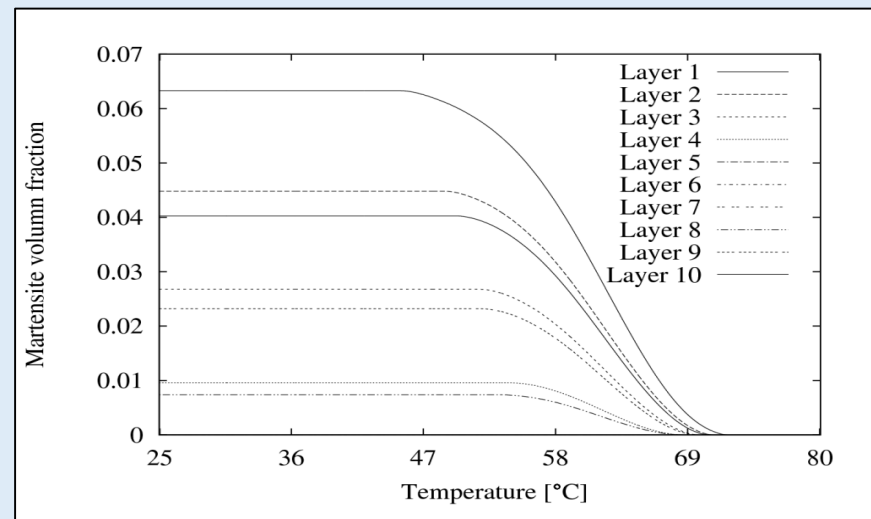
# 形状記憶合金を用いたハニカムアクチュエータの有限要素解析② [54.何・都井2013]



Process two: heat and actuating

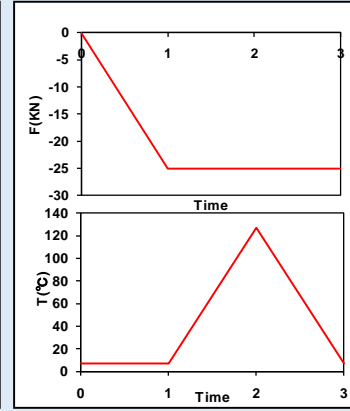
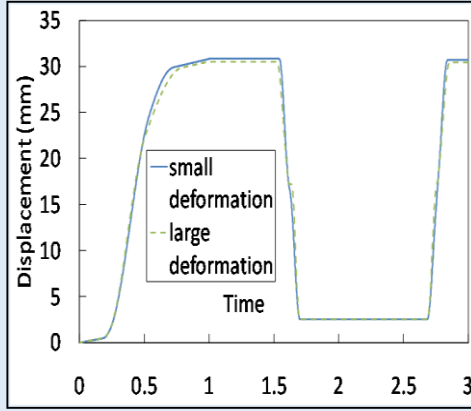
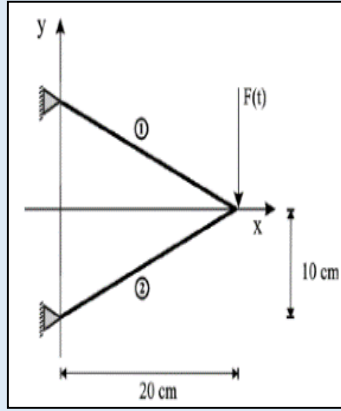


Actuating displacement [Okabe, 2011]



Martensite phase change in each layer of one element

# 形状記憶合金を用いた適応トラスの有限要素解析 [55.宮田・都井2013, 56.都井・塚本2011]

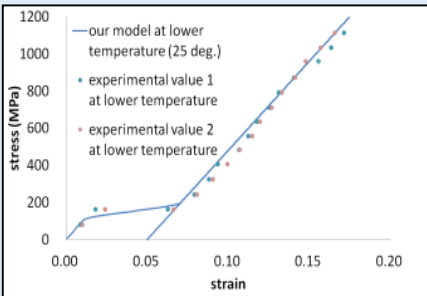
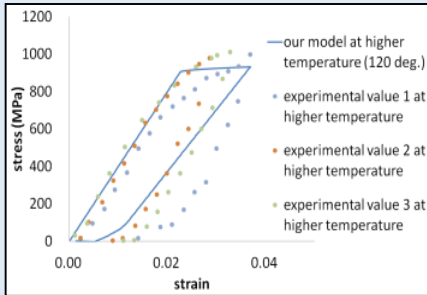
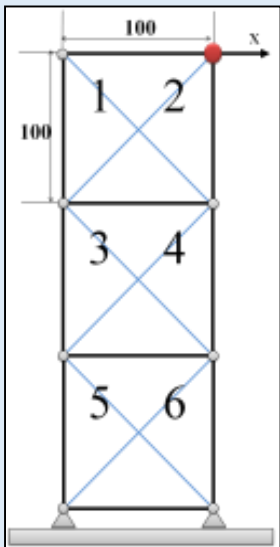


Parabola antenna Space structure

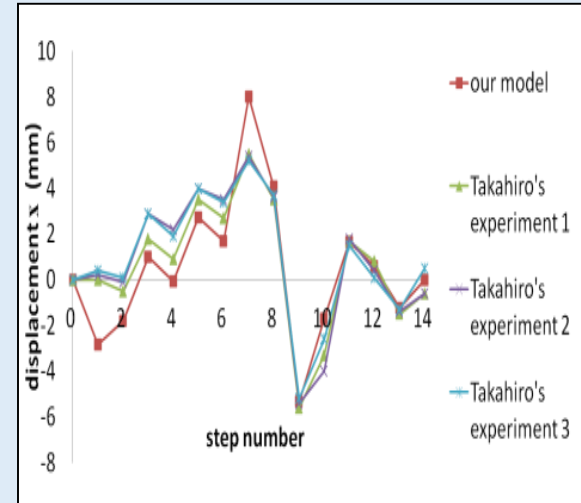
2D two-bar adaptive truss (①, ②: SMA)

Time-history of displacement

Time-history of load and temperature



Step	1	2	3	4	5	6	7
State	H	C	H	C	H	C	H
member	1	1	4	4	6	6	2 4 6
Step	8	9	10	11	12	13	1 4
State	C	H	C	H	C	H	C
member	246	135	135	146	146	145	1 4 5



Adaptive truss structure

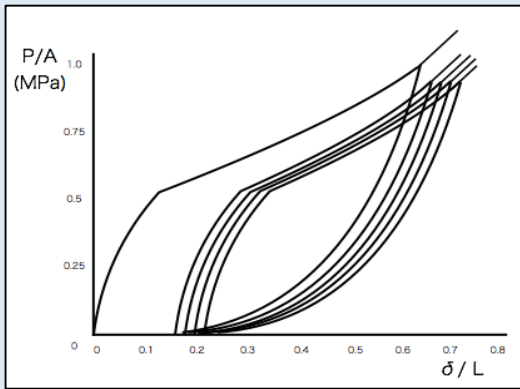
Identified stress-strain curves a) 120°C (upper) b) 25°C (lower) [Takahiro, 2010]

Step number and state (H=heating, C=cooling)

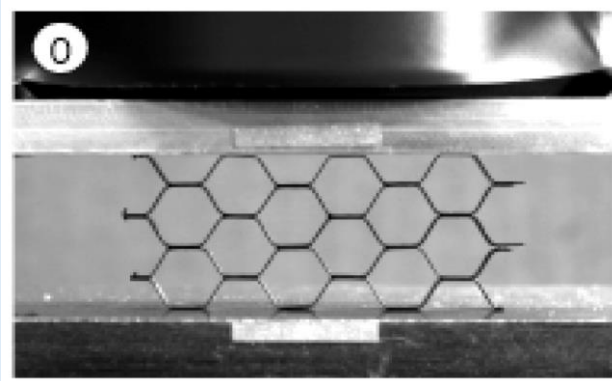
Comparison of calculated nodal displacement history with experiment [Takahiro, 2010]



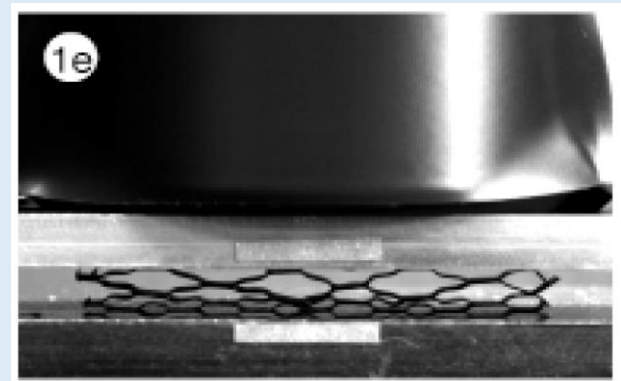
# 有効要素長を考慮したASI法による形状記憶合金ハニカム超弾性解析 [58.都井・成田2015]



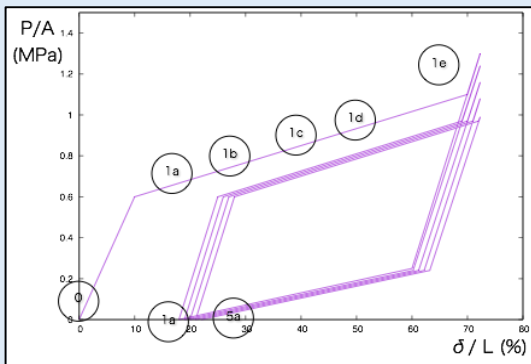
Experimental load-displacement curve [Shaw, 2007]



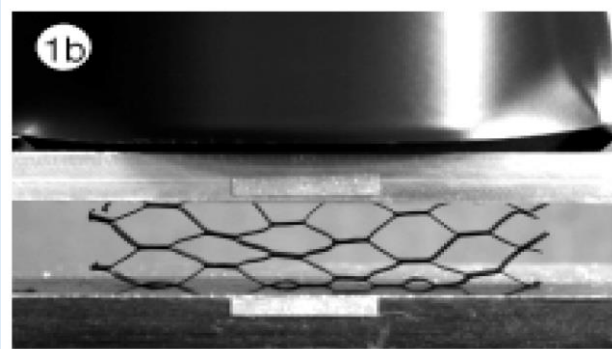
①



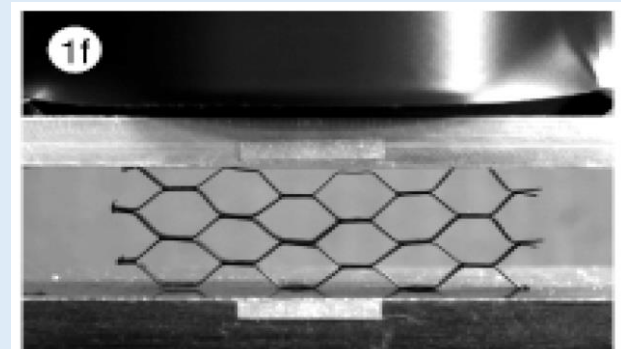
③



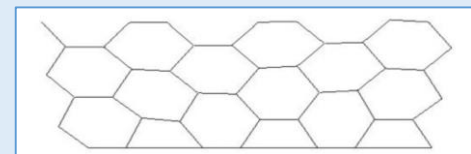
Calculated load-displacement curve



②



④



Experimental [Shaw, 2007] and calculated superelastic deformation process of shape memory alloy honeycomb core