University of Toronto – Department of Mechanical and Industrial Engineering

MIE1740H1S Smart Materials and Structures **Final 2021**

Date: April 18, 2021 **Duration: 48 hours**
Instructor: Professor Hani Naguib **Exam Type: Take home exam**
Deadline: April 20 at 04:00 PM to be submitted on Quercus (assignment)

EXAM Instructions

Open Book Exam. Any course-related resources can be used. Avoid any internet resources.

Answer all the questions either on paper or digitally, make sure to package your answers in a SINGLE pdf file before submission on Quercus.

Paper answers: ensure a clear scanned/photo version of your answer sheets.

Answer the questions in your OWN WORDS.

Use YOUR OWN sketches and graphs as often as possible to clarify your answers.

State formulas and constants whenever applicable.

Answer the questions in the context of the course material and tutorials.

Do the best you can with the way the questions are worded, make assumptions if needed.

Max 10 pages including schematics, 12 font size, single spacing.

NO LATE submissions are accepted.

Plagiarism or any other form of cheating is subject to serious academic penalty according to:

https://www.academicintegrity.utoronto.ca/

"In submitting this [quiz, exam or assignment] (circle one), I confirm that my conduct during this [quiz, exam or assignment] adheres to the Code of Behaviour on Academic Matters. I confirm that I did NOT act in such a way that would constitute cheating, misrepresentation, or unfairness, including but not limited to, using unauthorized aids and assistance, personating another person, and committing plagiarism."

(student name/student number/date) ________________________________

Signature ________________________________

1. a) Compare between shape memory alloys, shape memory polymers and shape memory ceramics in terms of :

[10 marks]

- Microstructure properties
- Fabrication and training
- Actuation mechanisms
- Output parameters (i.e. force, strain, response time)
- State 2 potential applications for each

b) Derive a one dimensional constitutive model for shape memory alloys and apply it to determine the maximum strain of a NiTi wire (with 70% martensite phase) if the elastic modulus is 24 GPa, the coefficient of linear thermal expansion is 11 x 10^{-6} K^{-1}, the maximum transformation strain is 12%, and the reorientation stress is 200 MPa. (Please assume any other fitting parameters or variables) [10 marks]

2. a) Design a new dielectric elastomer transducer explaining: i) Maxwell stress effect, ii) electrode design and types iii) dielectric materials design (state two different configuration), and what will be the dielectric materials used, size and thickness for the best optimum performance.

[10 marks]

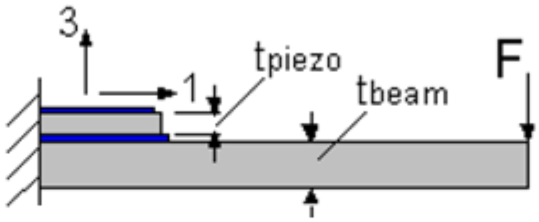
b) A dielectric elastomer transducer is designed to be used as a medical tourniquet that can strain up to 30% of its original shape. The transducer is made of silicone material with a modulus of elasticity of 200 MPa and relative dielectric constant of 2. Determine the electric field required to activate the transducer knowing that the permittivity of free space is 8.85×10-^{12} F/m. [10 marks]

3. a) Compare between the doping mechanisms of conductive polymers and ionic polymers metals composites including their methods of actuations. Show the design and components of a trilayer actuator based on the two different materials. Give two example applications.

[10 marks]

b) Part i. A patch of PZT thin film is located near the base of a cantilever beam as shown below. The PZT film is vertically sandwiched between two conductive electrodes and operates in d_{31} mode. The length of the entire beam is $l_b = 12cm$, the thickness is $t_b = 4mm$ and the width is $w_b = 12mm$. The length of piezo PZT is $l_p = 2cm$, the thickness is $t_p = 0.4mm$ and the width is $w_p = 12mm$. If a force, $F = 12N$, is applied, determine the voltage V generated. The dielectric constant of PZT is 1200, the permittivity of free space is 8.854x10^{-12} F/m and the piezoelectric modulus d_{31} is -110x10^{-12} m/V.

Part ii. What would be the voltage generated in the same situation as above, if you were to replace the PZT piezoelectric with a PVDF polymer piezoelectric with the same dimensions but different properties. The dielectric constant of PVDF is 12 and the piezoelectric modulus d_{31} is 23x10^{-12} m/V. [10 marks]



Hint:

$$T = \frac{F l_b t_b}{2 I_b} \qquad I_b = \frac{w_b t_b^3}{12} \qquad V = \frac{d_{31} T t_p}{\varepsilon}$$

4. a) Define Bingham Model and qualitatively state how to determine the different parameters in the model. Design a magneto rheological fluid system showing your selection of materials and show the effect of particle type and size, and carrier on the materials behavior. Give two example applications of Magnetorheological Fluids. [10 marks]

   b) Compare in details with the aid of sketches the three mechanisms of activation of Azobenzene and the various photo responses of these materials showing the molecular effect and transitions. Give one example application for each mechanism. [10 marks]

5. It is required to design a smart materials based prosthetic hand with self healing capability. [20 marks]

   a) State the design requirements of the new prosthetic.
   b) Describe the detailed design of the prosthetic mechanism showing the various components (power, actuators, sensors). Be specific.
   c) Explain your material selection procedure and justify your choice of materials by stating material requirements and how your material is capable of meeting the requirements.
   d) Based on your material selection, recommend and explain fabrication/synthesis that you will be considering for these materials in terms of making the raw materials as well as the final form that is required for your design.
   e) Estimate quantitatively the input and output parameters for the new prosthetic (make the necessary assumptions).

Mechanical & Industrial Engineering
UNIVERSITY OF TORONTO

Final Exam: MIE 1740 – Smart Materials and Structures, 2019

Student Name:	**Student Number:**

Time: 2.5 hours **April 16, 2019** **Total Value 100Pts**
Instructors: Professor Hani Naguib, Gary Sun
Closed book exam. Only one handwritten AID SHEET are allowed.
No electronic agendas are allowed. Strictly no exceptions.
Answer all the questions in the EXAM BOOKLETS.
Answer the questions in your OWN WORDS
Use SKETCHES and GRAPHS as often as possible to clarify your answers.
Do the best you can with the way the questions are worded.

1. a) Draw the 3D shape memory cycles for both shape memory alloys and shape memory polymers and compare them in terms of :

   [10 marks]

   - Actuation mechanisms
   - Output parameters (i.e. force, strain, response time)
   - Applications (state two applications for each)

   b) Determine the maximum strain of a single, unloaded NiTi wire which is cooled 60°C to form 80% martensite phase. The elastic modulus is 22 GPa, the coefficient of linear thermal expansion is 10.4 x 10^{-6} K^{-1}, the maximum transformation strain is 15%. Assume any other fitting parameters or variables. [10 marks]

$$\varepsilon = \frac{\sigma}{E} + \alpha(T - T_S) + \xi\gamma_m$$

2. Compare the following two classes of electroactive material: dielectric elastomers and conductive polymers in terms of the following: [10 marks]

   - What are the inputs and output parameters for each class of material? Provide reasonable estimate values.
   - Describe the components and microstructure present in each material class.
   - Describe the actuation mechanism for each class.
   - Would each material be suited for direct sensing applications and how?

b) A dielectric elastomer transducer is designed so that it can strain up to 10% of its original shape. The transducer is made of silicone material with a modulus of elasticity of 2.6 MPa and relative dielectric constant of 3.5. Determine the electric field required to activate the transducer knowing that the permittivity of free space is 8.85 x 10^{-12} F/m. [10 marks]

$$s = \frac{\varepsilon\varepsilon_0 E^2}{Y}$$

3. a) In your own way define the following terms in the context of the smart materials and structures subject. [10 marks]

- Corona poling
- Superconductivity
- Dielectric breakdown
- Bingham body model
- Rate of electrolysis in gels

b) Complete the following table in your booklets comparing the different smart materials learned in class. Where possible try to give quantitative ranges. [10 marks]

	Activating Potential	Stress	Strain	Time response
Nitinol (Ni-Ti)				
Polypyrrole (PPy)				
PVDF				
Lead Zinc Titanate (PZT)				
Chemo-mechanical Polymer Gels				

4. a) Explain in details the mechanisms of ferromagnetic gels. What are the criteria for designing and selecting the polymers resin? [10 marks]

b) Using the Bingham Model design a magneto rheological fluid system, qualitatively stating how to determine the different parameters in the model. Justify your selection of materials and show the effect of particle type and size, and carrier. [10 marks]

5. a) Describe the phenomenon of photo deformability of the chromophores upon exposure to a polarized light source and hence the actuation of these optically activated materials. [10 marks]

b) Explain the mechanism of water uptake and release in pH activated materials. Describe two potential applications for these materials. [10 marks]

DEPARTMENT OF MECHANICAL AND INDUSTRIAL ENGINEERING

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FACULTY OF APPLIED SCIENCE AND ENGINEERING

UNIVERSITY OF TORONTO

Final Exam: MIE 1740 – Smart Materials and Structures

Student Name:	**Student Number:**

Time: 2 hours **April 13, 2016** **Total Value 100Pts**
Instructor: Professor Hani Naguib
CLOSED BOOK EXAM. One Aid handwritten sheet allowed
No electronic agendas are allowed.
Answer all the questions in the EXAM BOOKLETS.
Use SKETCHES and GRAPHS as often as possible to clarify your answers.
Do the best you can with the way the questions are worded.

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1. a) Compare between shape memory alloys and shape memory ceramics in terms of : [10 marks]

   - Thermomechanical properties
   - Microstructure properties
   - Output parameters (i.e. force, strain, response time)
   - Applications

   b) Derive a one dimensional constitutive model for shape memory alloys and apply it to determine the maximum strain of a NiTi wire that is cooled from 60°C to an 80% martensite phase, if the elastic modulus is 22 GPa, the coefficient of linear thermal expansion is 10.4 x 10^{-6} K^{-1}, the maximum transformation strain is 15%, and the reorientation stress is 250 MPa. (Please assume any other fitting parameters or variables) [10 marks]

2. a) You are required to design a piezoelectric system for vibration damping, explain the mechanisms of activation showing their actuation and sensing behaviors, explain the formulas and state two applications. [10 marks]

b) A square shaped piezoelectric material with 10 mm of side length has piezoelectric strain coefficient of 400 X 10^{-12} m/V and a mechanical compliance of 20 X10^{-12} m^2/N. Determine i) the strain produced by a force of 200 N applied to the face of the material when the applied electric field is zero. ii) the electric field required to produce an equivalent amount of strain when the applied stress is equal to zero. [10 marks]

3. a) Define the concept of the dielectric elastomer transducer explaining: i) Maxwell stress effect, ii) electrode design and types iii) dielectric materials design (state two different configuration), and what will be the dielectric materials used, size and thickness for the best optimum performance. [10 marks]

b) A dielectric elastomer actuator has an elastic modulus of 15 MPa and relative dielectric constant of 5. i. Compute the strain of the material if it is actuated by an electric field of 100MV/m. ii. Compute the blocked stress of the actuator that is 50μm thickness and applied potential of 2KV. Assume that the materials are incompressible.
[10 marks]

4. a) Compare between Magnetic Ferrogels and Magnetorholeogical fluids in terms of the following: stiffness, output strain, particle size and particle dispersion. Give example of each materials system. [10 marks]

   b) Using the Bingham Model design a magneto rheological fluid system, qualitatively stating how to determine the different parameters in the model. Justify your selection of materials and show the effect of particle type and size, and carrier. [10 marks]

5. a) Describe the phenomenon of photo ***orientation*** of the chromophores upon exposure to a polarized light source and hence the actuation of these optically activated materials. [10 marks]

   b) You are required to design a self healing concrete, explain in details the mechanisms to be used and the choice of materials selection for the activation.
[10 marks]