

## *Smart Materials*

### *Problem set #3: Shape memory effect*

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#### **Problem 1:**

Assuming that the stress required to initiate martensitic transformation in a Nitinol wire increases linearly by 5 MPa for every  $1^{\circ}\text{C}$  increase in temperature, calculate the stress required to initiate martensitic transformation at  $50^{\circ}\text{C}$ . It is given that Nitinol undergoes martensitic transformation at a stress of 300 MPa at  $30^{\circ}\text{C}$ .

#### **Problem 2:**

A SMA wire shows a stress plateau during martensitic transformation from 350 MPa to 400 MPa. The strain increases from 0.02 to 0.05 during this plateau. Calculate the approximate work done per unit volume during the martensitic transformation.

#### **Problem 3:**

A Nitinol wire has a stress-induced martensitic transformation starting at 200 MPa at  $30^{\circ}\text{C}$  and ending at 500 MPa. The transformation stress increases by  $10\text{ MPa}/^{\circ}\text{C}$ . If the wire is heated to  $80^{\circ}\text{C}$ , determine the new stress required to start and complete the transformation. Calculate the stress required to start and complete the transformation at  $80^{\circ}\text{C}$ .

#### **Problem 4:**

The martensite start and finish temperatures ( $M_s$  and  $M_f$ ), the austenite start and finish temperatures ( $A_s$  and  $A_f$ ) and the slopes of the variation of  $M_s$  and  $M_f$  with stress ( $T$ ) i.e.,  $CM$  and the slope of variation of  $A_s$  and  $A_f$  with  $T$ , i.e.,  $CA$ , of a shape memory material are as follows:  $M_s = 25^{\circ}\text{C}$ ,  $M_f = 5^{\circ}\text{C}$ ,  $A_s = 29^{\circ}\text{C}$ ,  $A_f = 51^{\circ}\text{C}$ ,  $CA = 4.5\text{ MPa}/^{\circ}\text{C}$ ,  $CM = 11.3\text{ MPa}/^{\circ}\text{C}$ . The elastic modulus of the material is 15 GPa and it has a recovery strain of 8%. For this material compute the following:

- Calculate the martensitic fraction when the material is cooled to  $20^{\circ}\text{C}$  from  $25^{\circ}\text{C}$  in a zero-stress state.
- If the temperature is maintained at  $25^{\circ}\text{C}$ , determine the martensitic fraction when a tensile stress of 100 MPa is applied to the wire.

- The wire is heated above  $A_f = 51\text{ }^{\circ}\text{C}$ , and then cooled under zero stress to  $30\text{ }^{\circ}\text{C}$ . Subsequently, it is subjected to loading to activate the shape memory effect, leading to complete phase transformation, starting from point a to point e (as illustrated in the Figure below).

Calculate the stress and strain values at points a, b, c, and d on the stress-strain diagram.

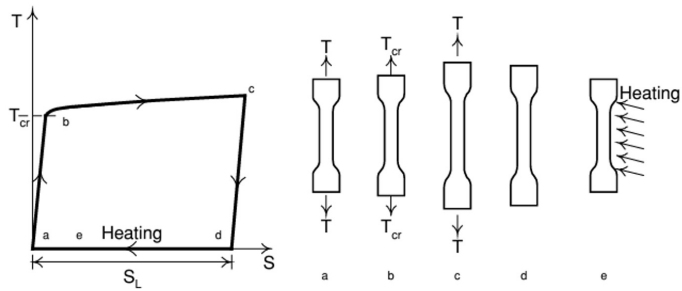


Figure 1:  
Strain-  
Stress  
curve