PURPOSE

To investigate some of the mechanical properties of the two NiTi phases and to try to relate these properties to the structure of each phase.

METHOD

So far, the phase transformation of NiTi has been accomplished by temperature cycling, but straining the material by applying stress also can initiate these transitions. Martensite is favored under high applied stress because it is marginally denser than austenite, a fact that was brought out in Investigation 2. Therefore, if we consider the composition of the alloy to be an equilibrium between these two phases, LeChatelier’s Principle should govern the behavior of the equilibrium under applied stress. LeChatelier's Principle predicts that an increase in pressure favors the denser phase. A bending motion applied to a metal rod would result in some atoms being compressed and some pulled apart. A force per unit area, or pressure, is exerted on the atoms in the region of the compression. As a result, this increase in pressure should result in a transition to the more dense, martensite phase, as predicted by LeChatelier’s Principle.

An analogy would be to consider the phase diagram for water. The line that separates the liquid and gaseous phases exhibits a positive slope, and any point on that line represents an equilibrium between the two phases. Therefore, at any point on this line, if, at constant temperature, the pressure were to increase, the equilibrium would shift toward the liquid or denser phase. Releasing the stress will allow the reverse transformation to occur.

The two NiTi structures display markedly different mechanical properties. The cubic crystal structure of austenite results in its being relatively hard and inflexible, whereas the less symmetric structure of martensite with the ability to reorient variants in its structure, displays a greater flexibility and malleability. NiTi rods can illustrate the different mechanical properties of the two structures. Consider the idealized figure below.

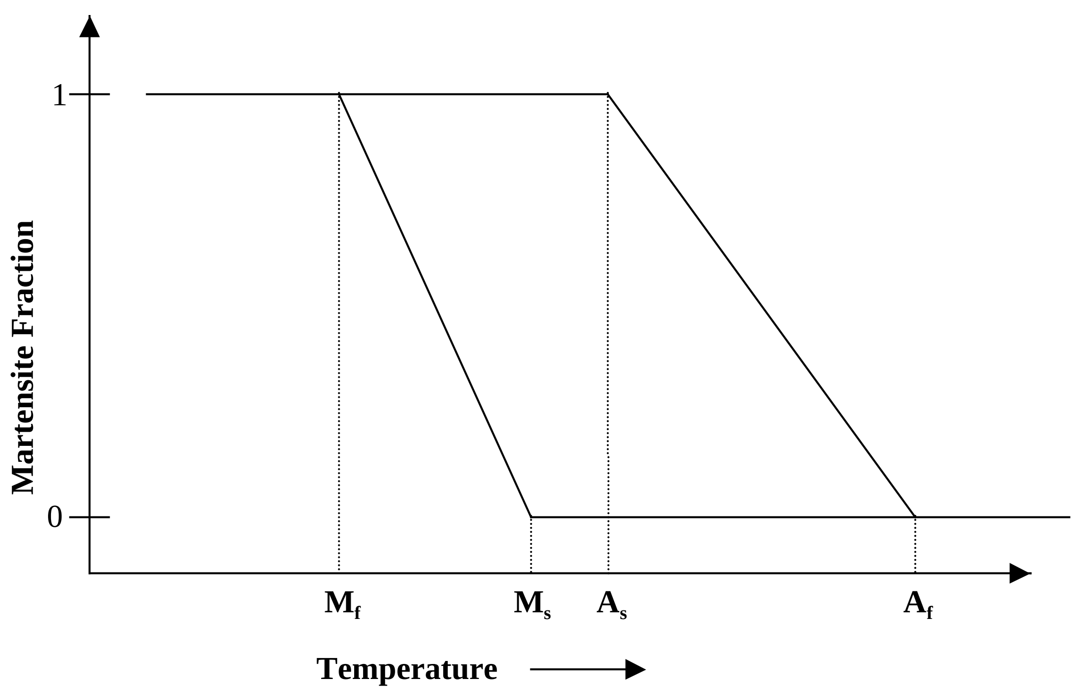

Figure 3: Taken from http//www.sma-inc.com/ttrmeas.html#dsc Smart Sheet #11:
There are four characteristic temperatures defining the martensite transformation. Starting at a high temperature in which the NiTi sample is exclusively in the austenite structure, the martensite start temperature, $\mathbf{M_s}$, is the temperature at which martensite first appears in the austenite. The transformation proceeds with further cooling and is complete at the martensite finish temperature, $\mathbf{M_f}$. Below $\mathbf{M_f}$, the entire structure is in the martensite phase, and a specimen typically consists of many regions each containing a different variant of martensite. The boundaries between the variants are mobile under small applied stresses. With heating, the austenite start temperature, $\mathbf{A_s}$, is the temperature at which austenite first appears in the martensite. With further heating, the sample continues its transformation into austenite, and this transformation is complete at the austenite finish temperature, $\mathbf{A_f}$. Above $\mathbf{A_f}$ the specimen is in the original undistorted state.

The samples used in this activity can be made to exist in either of the two phases at room temperature by carefully adjusting the composition of the rods. The Ni/Ti ratio is nominally 1:1, but the ratio may be modified by a few percent to control the temperatures at which the phase transformations occur.

MATERIALS

NiTi rods-one of each type per group (See supplier information in the Appendix)

hot water bath

liquid nitrogen (local sources include dermatologists, welders, universities, hospitals, research institutions). An alternative would be to use a dry ice and acetone bath.

tongs

gloves

heat gun (hair dryer)

PROCEDURE

Part I

a. Try bending each of the two rods provided by your instructor into a V-shape. Identify the rod that is inflexible. **Note: Caution students that the thickness of the rod prevents it from being bent into a complete V-shape.**

b. Cool the less flexible rod in liquid nitrogen or an alternative cooling bath (CAUTION), as directed by your instructor. Use tongs and gloves.

c. Remove the rod from the liquid nitrogen or alternative cooling bath. Then, while wearing gloves, bend the rod into a V-shape.

d. Allow the rod to warm back to room temperature.

Part II

e. Warm the flexible rod in water that has been heated to near the boiling point. Remove with tongs, and, while wearing gloves, try to bend it.

f. Allow the rod to cool and then try to bend it again.

Part III

g. Using the appropriate methods, return both rods to their original linear shapes.

h. Try scratching each rod with the other. **Note: Tell the students to expect a light scratch, not a gouge.**

ANSWERS TO FOLLOW-UP QUESTIONS

1. State your observations for step (a) of the procedure.

   One-rod bends easily, the other does not.

2. State your observations for step (d) of the procedure.

   The bent rod returns to its original shape when warmed to room temperature.

3. State your observations for step (e).

   The more flexible rod becomes difficult to bend.

4. State your observations for step (f).

   The rod is inflexible when warm and flexible when it returns to room temperature.

5. State your observations for step (g).

   Student responses. Need to heat the bent, low temperature rod.

6. State your observations for step (h).

   Austenite scratches martensite.

7. Based upon your observations, which rod was in the low temperature martensite phase and which was in the high temperature austenite phase?

   Flexible-martensite. Inflexible-austenite.

8. a) Which rod was harder than the other?

   Inflexible-austenite.

   b) Is this consistent with your answer to question (5)? Explain.

   Yes, inflexibility and hardness are related, at least, to a certain extent.

9. If you were to make a pair of eye-glass frames that could be easily restored to their original shape if accidentally sat upon:

   a) In which phase would you manufacture them?

Austenite for rigidity and strength.

b) Where would you adjust the transition temperature- above or below room temperature?

Below room temperature to ensure that the austenite phase is dominant at room temperature.

c) If your glasses were bent, what, if anything, would you do to return them to their original shape? Explain.

Nothing. The applied stress allowed them to transform into martensite and become flexible. Relieving the stress will allow them to return to their original shape.

d) What if they didn't fit exactly right? What would you need to do to adjust them?

Heat them to candle flame temperature. Reshape them, then let them cool to room temperature.