Elastic properties:
Y_A = 67 GPa
Y_M = 26 GPa

Transformation Temperature
M_f = 9°C
M_s = 18°C
A_s = 35°C
A_f = 49°C

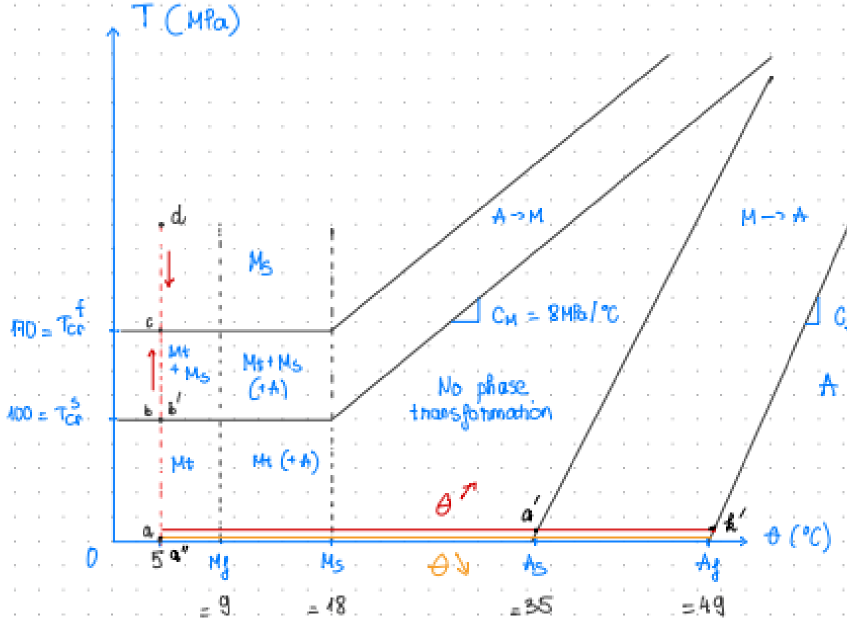
Transformation Constraints
C_M = 8 MPa/°C
C_A = 14 MPa/°C
T_{cr}^{s} = 100 MPa
T_{cr}^{f} = 170 MPa

Max Recovery Strain
ε_L = 0.07

Material Heat
θ = 5°C

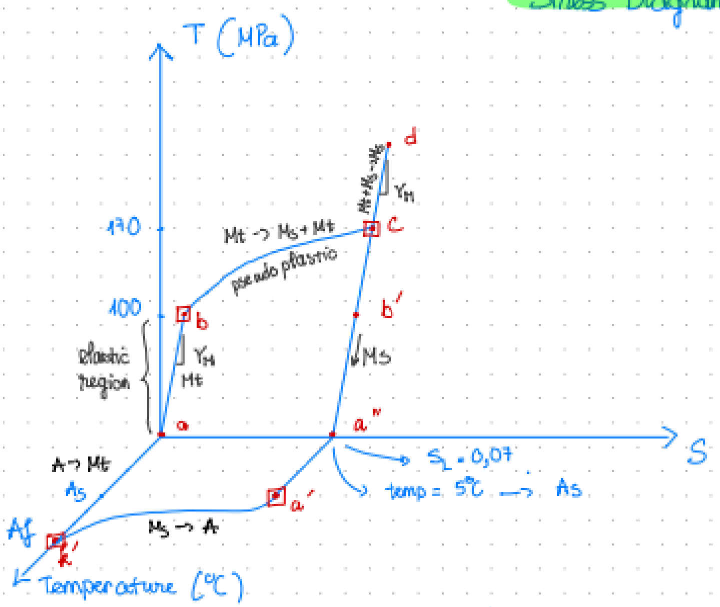
(1) What is the SMAs behavior at the given?
$\theta = 5°C < M_f = 9°C$ => The SMA behavior can be shape memory effect (SME)

(2) Draw stress cycle on phase diagram? (Phase Diagram)



(3) Sketch graphically T-S curve with different specific regions?
-> Determined transitional points: b,c

Stress Diagram



(4) Evaluate stress at the transitional points in the T-S curve?

- $\tau_b = T_{cr}^{s} = 100$ MPa
- $\tau_c = T_{cr}^{f} = 170$ MPa
- $\tau_{a'} = 0$
- $\tau_{k'} = 0$

} Stress free condition => Reverse martensitic transformation.
-> $\xi_0 = 1 \Rightarrow \xi_0 = \frac{1}{2}\left(1 + \cos\left[a_A^{*}(\theta - A_s)\right]\right)$

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Stress free condition => Reverse Martensitic Transformation

$$=> \xi_{M_s} = 1 => \xi_M = \frac{1}{2} * \left(1 + \cos\left(a_A * (\theta - A_s)\right)\right)$$

With:

$$a_A = \frac{\pi}{(A_f - A_s)}$$

Code File:

```
import math
import numpy as np
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D

class Shape_Memory_Effect:
  def __init__(self, YA, YM, Ms, Mf, As, Af, CM, CA, TCRS, TCRF, SL, temp, shiS0, shiT0):
    self.YA = YA
    self.YM = YM
    self.Ms = Ms
    self.Mf = Mf
    self.As = As
    self.Af = Af
    self.CM = CM
    self.CA = CA
    self.TCRS = TCRS
    self.TCRF = TCRF
    self.SL = SL
    self.temp = temp
    self.shiS0 = shiS0
    self.shiT0 = shiT0
    self.shi_lst = []

  def stress_calculated(self):
    global Ta, Tb, Tc
    Ta = 0
    Tb = self.TCRS
    Tc = self.TCRF
```

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```
def predicted_through_stress(self):
    global Tb_predicted, Tc_predicted, Td_predicted, Taf_predicted, Tkf_predicted, Ta_predicted
    Tb_predicted = np.linspace(Ta, Tb, 20)
    Tc_predicted = np.linspace(Tb, Tc, 20)
    for i in Tc_predicted:
        shiS = ((1 - self.shiS0) / 2) * math.cos((math.pi / (self.TCRS - self.TCRF)) * (i - self.TCRF)) + ((1 + self.shiS0) / 2)
        self.shi_lst.append(shiS)
    self.shi_lst = np.array(self.shi_lst)
    Td_predicted = np.linspace(Tc,Ta,num=20, endpoint=True)
    Taf_predicted = np.linspace(0,0, num=20, endpoint=True)
    Tkf_predicted = np.linspace(0,0, num=20, endpoint=True)
    Ta_predicted = np.linspace(0,0, num=20, endpoint=True)

def predicted_through_strain(self):
    global Sb_predicted, Sc_predicted, Sd_predicted
    Sb_predicted = Tb_predicted/self.YM
    Sc_predicted = (Tc_predicted/self.YM) + self.SL*self.shi_lst
    Sd_predicted = (Td_predicted/self.YM) + self.SL


def predicted_through_temp(self):
    global temp_b_predicted, temp_c_predicted, temp_d_predicted, temp_a_f_predicted, temp_k_f_predicted,
temp_a_predicted
    temp_b_predicted = np.linspace(self.temp,self.temp,num=20, endpoint=True)
    temp_c_predicted = np.linspace(self.temp,self.temp, num=20, endpoint=True)
    temp_d_predicted = np.linspace(self.temp,self.temp, num=20, endpoint=True)
    temp_a_f_predicted = np.linspace(self.temp, self.As, num=20, endpoint=True)
    temp_k_f_predicted = np.linspace(self.As, self.Af, num=20, endpoint=True)
    temp_a_predicted = np.linspace(self.Af, self.temp, num=20, endpoint=True)

def predicted_through_strain_by_temp(self):
    global strain_a_f_predicted, strain_k_f_predicted, strain_a_predicted
    # At a'
    strain_a_f_predicted = np.linspace(self.SL,self.SL, num=20, endpoint=True)
    # At k'
    shi_M_ls = []
    for i in temp_k_f_predicted:
        shi_M = 1/2*(1 + math.cos((math.pi/(self.Af-self.As))*(i-self.As)))
        shi_M_ls.append(shi_M)
```

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```
        shi_M_ls = np.array(shi_M_ls)
        strain_k_f_predicted = self.SL*shi_M_ls
        # At a
        strain_a_predicted = np.linspace(0,0, num=20, endpoint=True)

    def plot_T_S_Temp_curve(self):
        strain_combined = np.concatenate((Sb_predicted, Sc_predicted, Sd_predicted, strain_a_f_predicted, strain_k_f_predicted,
strain_a_predicted))
        stress_combined = np.concatenate((Tb_predicted, Tc_predicted, Td_predicted, Taf_predicted, Tkf_predicted,
Ta_predicted))
        temp_combined = np.concatenate((temp_b_predicted, temp_c_predicted, temp_d_predicted, temp_a_f_predicted,
temp_k_f_predicted, temp_a_predicted))

        fig = plt.figure(figsize=(12, 8))
        ax = fig.add_subplot(111, projection='3d')

        ax.plot(temp_combined, strain_combined, stress_combined, label='Stress-Strain-Temp Curve', color='blue')

        ax.set_xlabel('Temperature (°C)')
        ax.set_ylabel('Strain')
        ax.set_zlabel('Stress (MPa)')
        ax.set_title('Stress-Strain-Temperature Relationship')

        ax.set_zlim(0, 170)

        ax.legend()
        ax.grid(True)
        plt.show()


def main():
    Mf = 9  # °C
    Ms = 18  # °C
    As = 35  # °C
    Af = 49  # °C
    CM = 8  # MPa/°C (slope for martensite)
    CA = 14  # MPa/°C (slope for austenite)
    YM = 26000
    YA = 67000
    TCRS = 100  # MPa (start transformation stress)
```

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```
    TCRF = 170  # MPa (finish transformation stress)
    shiT0 = 1
    shiS0 = 0
    SL = 0.07
    temp = 5
    proc = Shape_Memory_Effect(YA, YM, Ms, Mf, As, Af, CM, CA, TCRS, TCRF, SL, temp, shiS0, shiT0)
    proc.stress_calculated()
    proc.predicted_through_stress()
    proc.predicted_through_strain()
    proc.predicted_through_temp()
    proc.predicted_through_strain_by_temp()
    proc.plot_T_S_Temp_curve()
if __name__ == "__main__":
    main()
```

Result:

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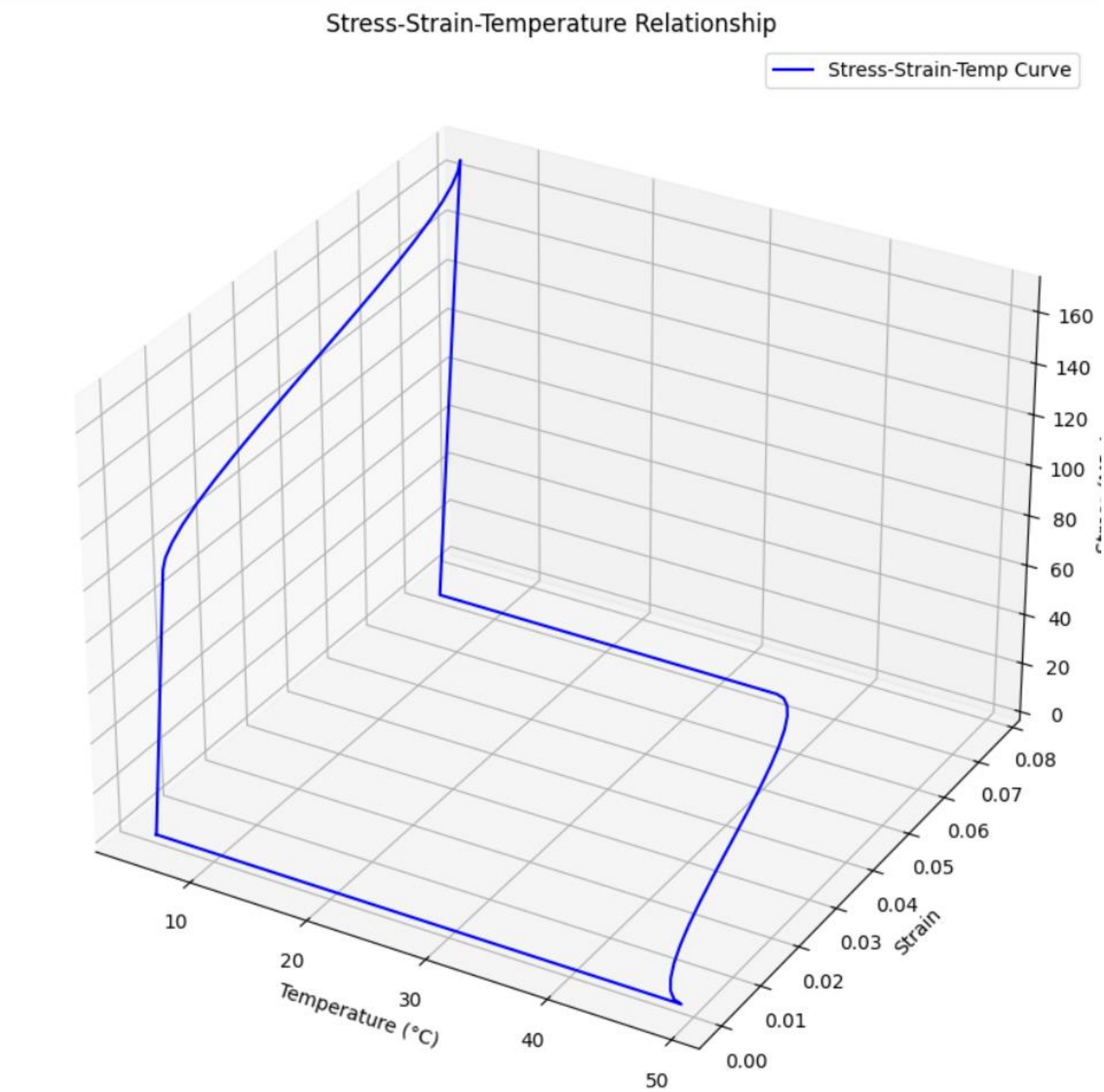

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