EFFECT OF TEMPERATURE ON THE PROPERTIES OF STRUCTURAL MATERIALS- CONCRETE, STEEL, MASONRY AND WOOD

Temperature significantly affects the properties of structural materials like concrete, steel, masonry, and wood. Here's a detailed look at each material and how temperature impacts its properties, including derivations where applicable:

1. CONCRETE

a) **Compressive Strength :** Concrete's compressive strength is influenced by temperature in the following ways:

i. Low Temperatures: At temperatures below freezing, the hydration process slows down. This can lead to incomplete curing and reduced strength. If the temperature is very low, the water in the mix can freeze, causing the formation of ice crystals that can damage the concrete structure. The strength gain of concrete is generally slower in cold weather.

ii. High Temperatures : At high temperatures (above 30°C or 86°F), the hydration rate increases, which can lead to a faster setting time and potential for thermal cracking if not managed properly. High temperatures can also lead to a higher rate of evaporation of water from the surface, which can cause surface defects and reduce the overall strength if not adequately cured.

The strength of concrete can be described by the general relationship:

$$f_c(T) = f_{c,20} \cdot (1-\alpha\cdot(T-20))$$

Where:

- $f_c(T)$ is the compressive strength at temperature T (°C),
- $f_{c,20}$ is the compressive strength at 20°C,
- α is a temperature coefficient (which can vary based on mix and conditions).

b) **Thermal Expansion:** Concrete expands and contracts with temperature changes. The coefficient of thermal expansion (CTE) for concrete is approximately 10×10^{-6} per °C.

The change in length (ΔL) due to temperature change (ΔT) is given by:

$$\Delta L = L_0 \cdot \alpha \cdot \Delta T$$

Where:

- L_0 is the original length,
- α is the coefficient of thermal expansion,
- ΔT is the change in temperature.

2. Steel

a) Strength and Modulus of Elasticity

i. Low Temperatures: Steel becomes more brittle at low temperatures. The yield strength of steel increases with decreasing temperature, but ductility decreases. The modulus of elasticity (E) is less affected by temperature changes compared to strength but does slightly decrease at very high temperatures.

ii. High Temperatures: At high temperatures (above 500°C or 932°F), the strength of steel decreases significantly. The yield strength decreases by about 50% at 600°C. Steel also experiences thermal expansion and softening.

The general relationship for the reduction in strength with temperature is:

$$f_y(T) = f_{y,20} \cdot e^{-\beta \,.\, (T-20)}$$

Where:

- $f_y(T)$ is the yield strength at temperature TTT,
- $f_{y,20}$ is the yield strength at 20°C,
- β is a material - specific temperature coefficient..

b) Thermal Expansion

The CTE for steel is about 12×10^{-6} per °C. The change in length (ΔL) due to temperature change (ΔT) is:

$$\Delta L = L_0 \cdot \alpha \cdot \Delta T$$

Where for steel is approximately 12×10^{-6} per °C.

3. Masonry

a) Compressive Strength:

i. Low Temperatures: Like concrete, masonry units (such as bricks and blocks) can suffer from frost damage if water in the units or mortar freezes. This can reduce the effective strength of masonry.

ii. High Temperatures: Exposure to high temperatures can cause thermal expansion, leading to thermal stresses and potential cracking. Prolonged exposure can also reduce the strength of masonry by degrading the mortar and affecting the bonds between units.

The general effect of temperature on masonry strength is less straightforward and often requires empirical testing. However, a simplified approach is:

$$f_m(T)=f_{m,20} \cdot (1-\gamma \cdot (T-20))$$

Where:

- $f_m(T)$ is the compressive strength of masonry at temperature T,
- $f_{m,20}$ is the compressive strength at 20°C,
- γ is a temperature coefficient (varies with material).

b) Thermal Expansion

The CTE for masonry is about 5×10^{-6} per °C. The change in length (ΔL) due to temperature change (ΔT) is:

$$\Delta L=L_0 \cdot \alpha \cdot \Delta T$$

Where for masonry is approximately 5×10^{-6} per °C.

4. Wood:

a) Strength and Modulus of Elasticity:

i. Low Temperatures: Wood becomes more brittle at low temperatures, and its strength can increase slightly due to reduced moisture content. However, excessive cold can cause problems like drying and cracking.

ii. High Temperatures: At high temperatures (above 70°C or 158°F), wood starts to lose strength significantly. The modulus of elasticity decreases as wood softens and loses its structural integrity.

The relationship between strength and temperature is less linear and varies based on wood species and moisture content. A simplified relationship might be:

$$f_w(T)=f_{w,20} \cdot (1-\delta \cdot (T-20))$$

Where:

- $f_w(T)$ is the strength of wood at temperature T,
- $f_{w,20}$ is the strength at 20°C,
- δ is a temperature coefficient.

b) Thermal Expansion:

Wood's CTE is about 3×10^{-6} per °C in the direction of grain and even lower perpendicular to the grain. The change in length (ΔL) due to temperature change (ΔT) is:

$$\Delta L = L_0 \cdot \alpha \cdot \Delta T$$

Where α for wood is approximately 3×10^{-6} per °C.

Summary:

Temperature affects each structural material differently, and understanding these effects is crucial for designing structures that can withstand varying thermal conditions. Each material has its own coefficients and empirical relationships that need to be considered to ensure structural integrity across different temperature ranges.