

# CE 415

# DESIGN OF STEEL STRUCTURES

## LECTURE 6

## RESIDUAL STRESS

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# OUTLINE

- What is residual stress?
- Residual stress graphical representation
- Residual stress math problem

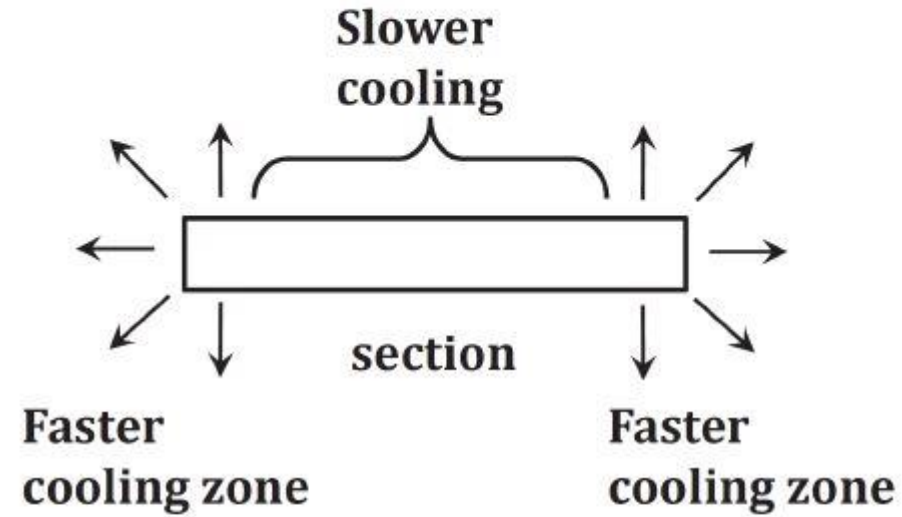
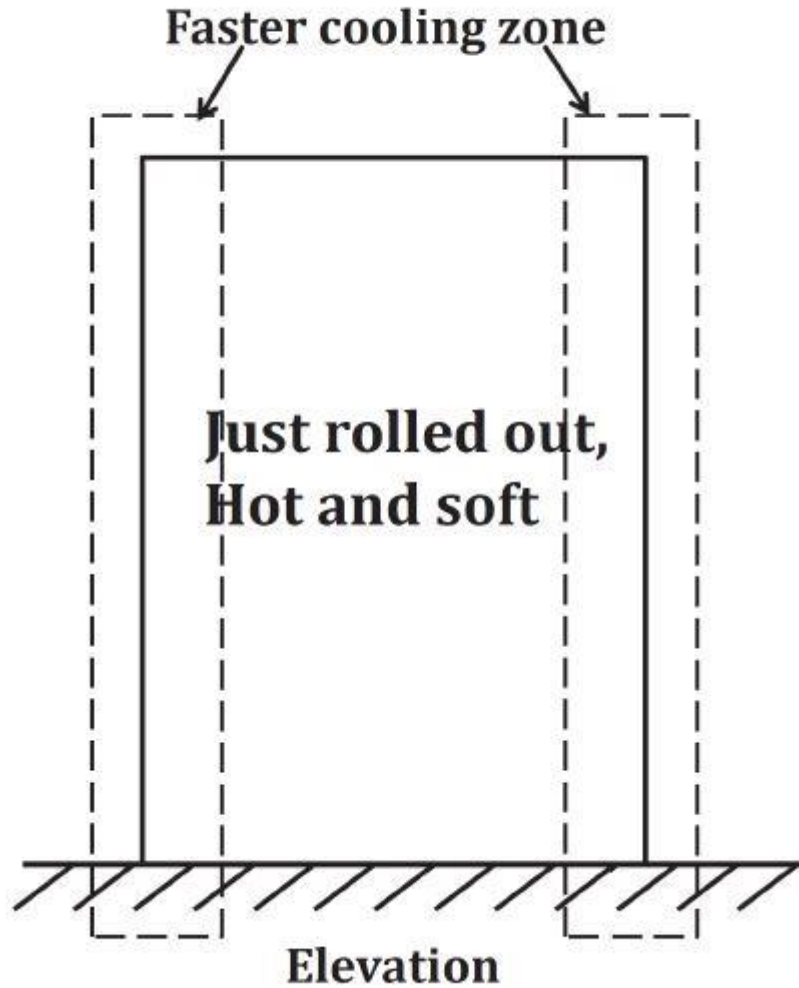
## **RESIDUAL STRESS IN STEEL SECTIONS**

**Residual stresses are self balancing stresses that remain in a member without application of load after it has been formed/rolled into a finished product.**

### **Sources of residual stresses:**

- Uneven cooling which occurs after hot rolling of structural shapes**
- Cold bending or cambering during fabrication**
- Punching of holes and cutting operations during fabrication**
- Welding**

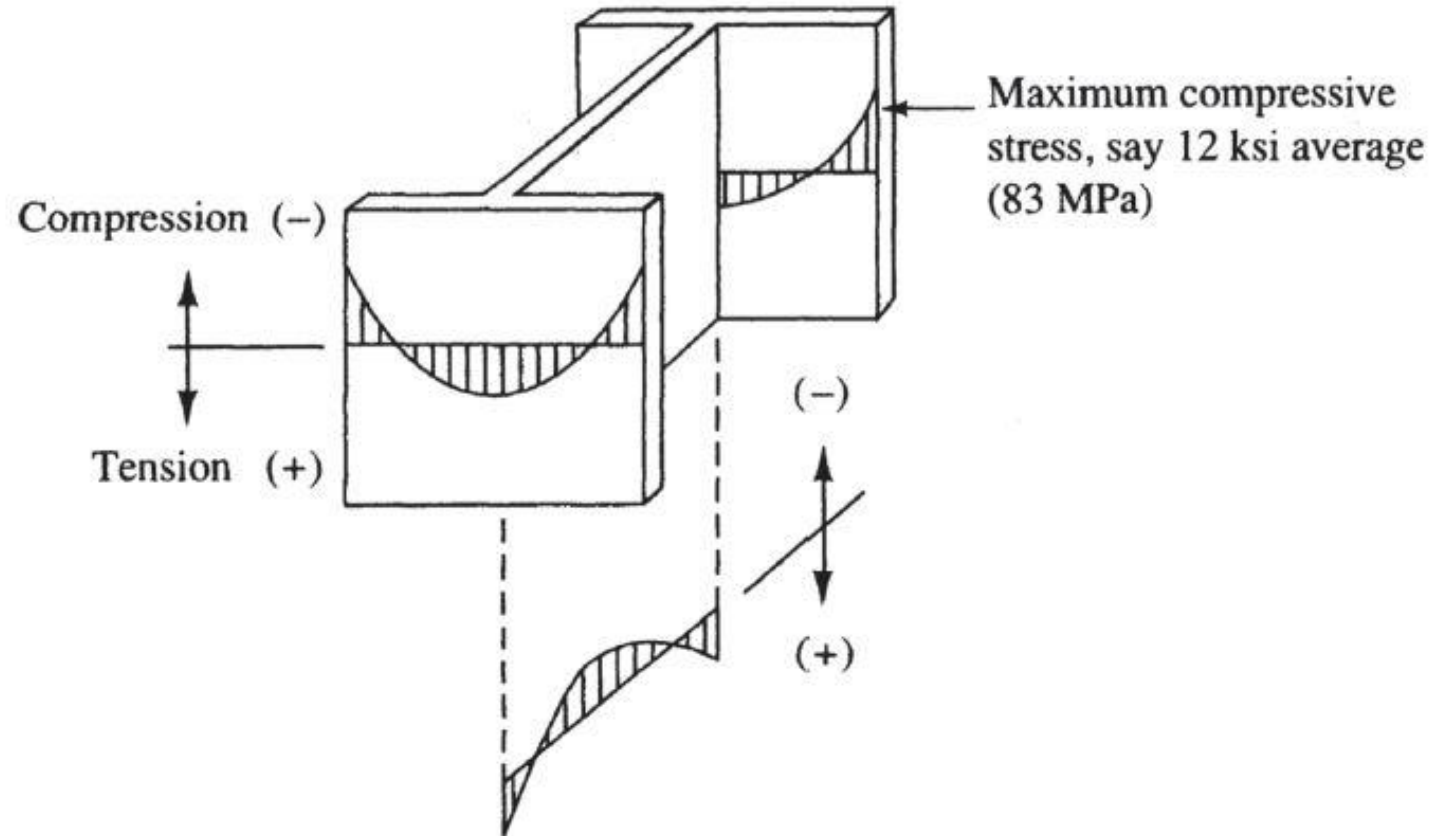
## RESIDUAL STRESS IN ROLLED FLAT BAR



Two edges of the flat bar shall cool down faster due to radiation of heat in three directions. The middle part shall cool slower due to radiation in two direction only.

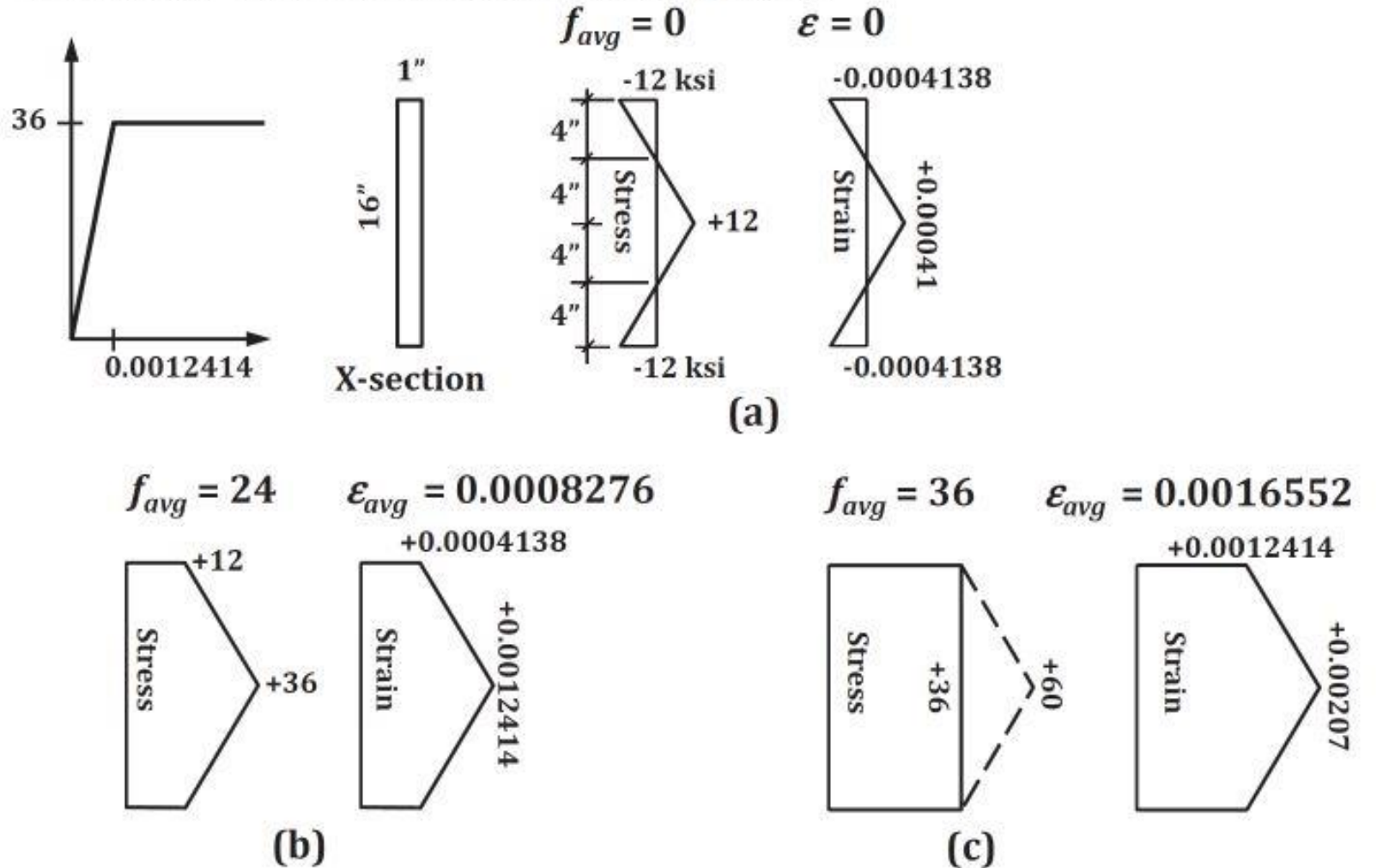
## RESIDUAL STRESS IN ROLLED SECTIONS

### Typical residual stress distribution in rolled shapes



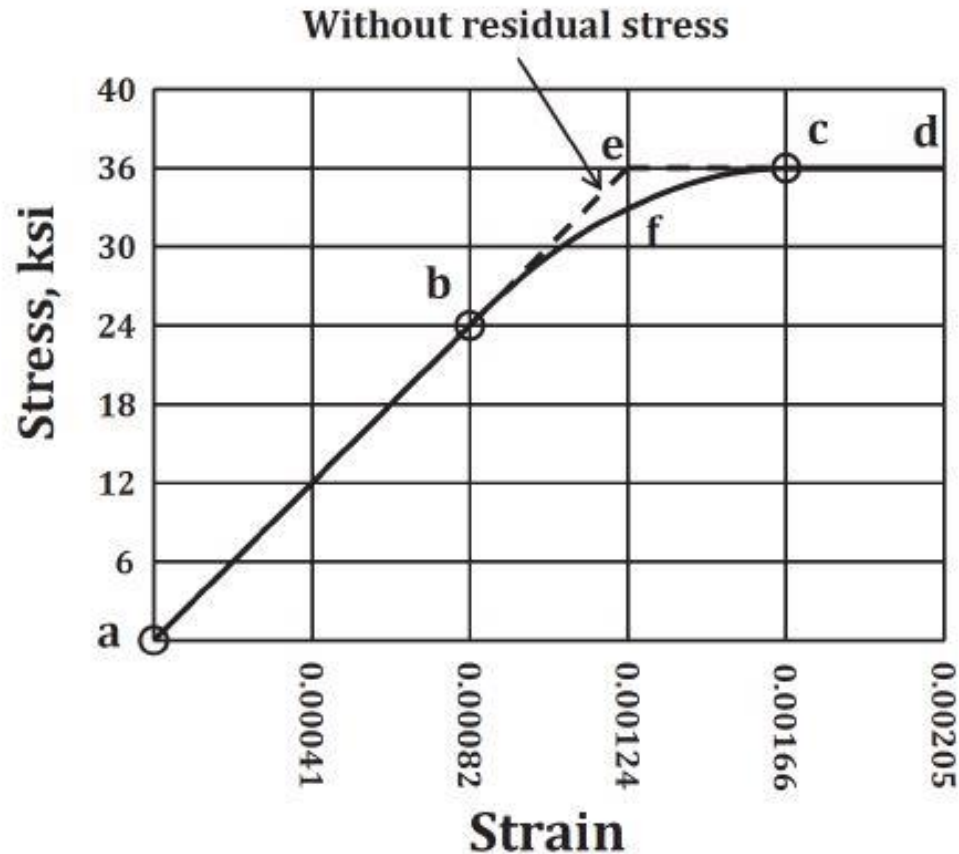
**Average tensile stress-strain relation of a 16"x1" x-section flat bar having residual stress.**

Distribution of residual stress and strain are shown in Fig. (A) when no external force acts. The bar is then gradually pulled.



## RESIDUAL STRESS IN STEEL SECTIONS

Average tensile stress-strain relation of a 16"x1" x-section flat bar having residual stress.



Due to presence of residual stress/strain the average stress-strain behavior follows path a-b-f-c-d

If there was no residual stress then the path would be a-b-e-c-d

## Equation of Stress-Strain Curve:

Up to point b, the stress-strain relation is linear. After c, the curve is flat. The transition from b to c can be covered by one parabolic curve as follows:

$f = k_1 \varepsilon^2 + k_2 \varepsilon + k_3$  Here,  $f$  is stress and  $\varepsilon$  is strain.

The constants  $k_1$ ,  $k_2$  and  $k_3$  can be found from three conditions:

- 1) At b,  $df/d\varepsilon = E = 29000$ , when  $\varepsilon = 0.0008276$  where  $E$  is the Young's modulus.
- 2) At b,  $f = 24$  when  $\varepsilon = 0.0008276$
- 3) At c,  $f = 36$  when  $\varepsilon = 0.0016552$

Now,  $df/d\varepsilon = 2k_1\varepsilon + k_2$ ,  $\therefore$  from (1),  $2k_1(0.0008276) + k_2 = 29000$  -----(1)

From (2),  $k_1(0.0008276)^2 + k_2(0.0008276) + k_3 = 24.0$  -----(2)

From (3),  $k_1(0.0016552)^2 + k_2(0.0016552) + k_3 = 36.0$  -----(3)

Solving the above three,

$$k_1 = -17520833.3, \quad k_2 = +58000.48, \quad k_3 = -12$$

Therefore,

$$\begin{aligned} f &= +29000\varepsilon && \text{for } 0 \leq \varepsilon \leq 0.0008276 \text{ [portion a-b]} \\ f &= -17520833.3\varepsilon^2 + 58000.48\varepsilon - 12 && \text{for } 0.0008276 \leq \varepsilon \leq 0.0016552 \text{ [portion b-f-c]} \\ f &= +36 && \text{for } \varepsilon \geq 0.0016552 \end{aligned}$$

Check: ideally at c,  $df/d\varepsilon = 0$

Check at e,  $df/d\varepsilon = 2(-17520833.3)(0.0016552) + 58000.48$   
 $= -0.49 \rightarrow$  very small compared to  $E = 29000 \rightarrow$  OK.