Welding Technology
ME692

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Stresses in welding

Stresses in Welding

- ✓ Stress is the internal resistance, or counterforce, of a material to the distorting effects of an external force or load.
- ✓ Most stresses that appear in a material arise from a mechanical source.
- ✓ Stresses can also arise from thermal sources; when they do, they are called **thermal stress** or **thermally induced stresses**.

Thermal stresses

https://www.youtube.com/shorts/kPnTlbGM1Q0

Thermal stresses

Thermal stresses

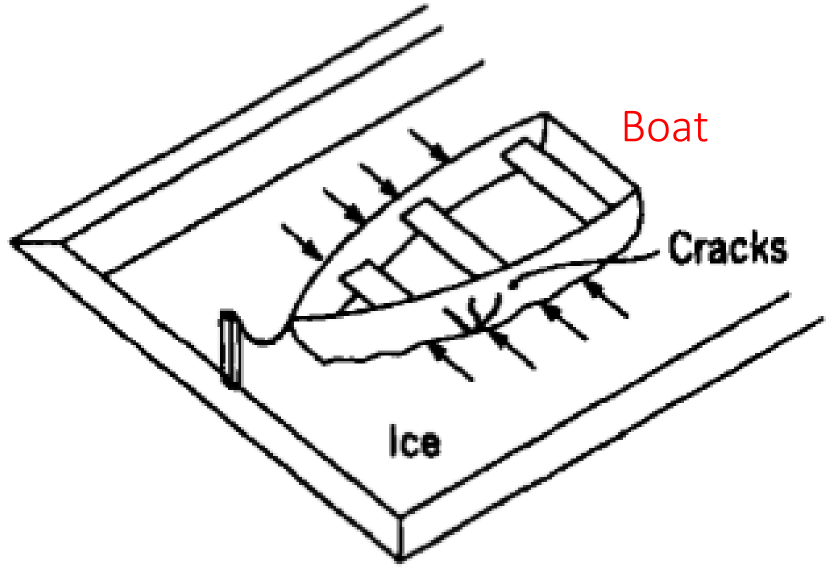
Stresses in Welding

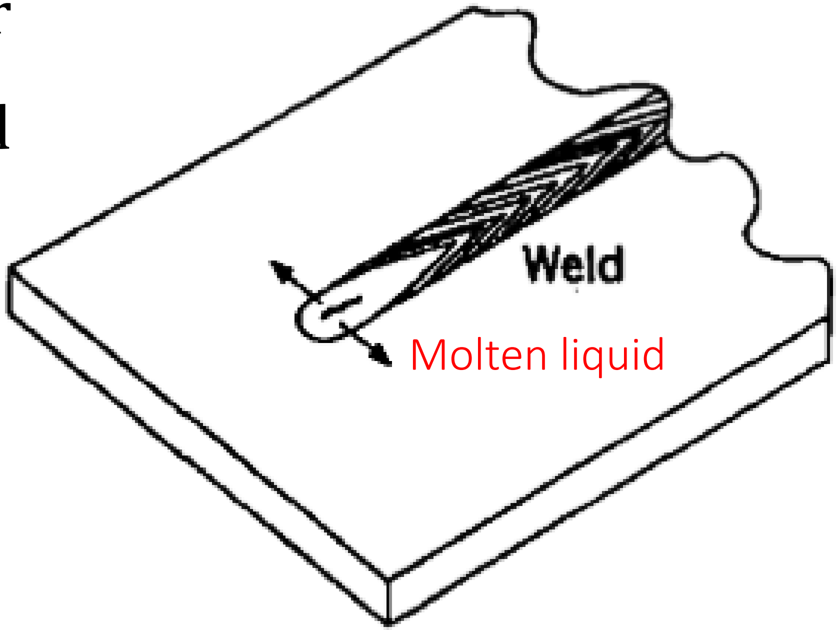
- ✓ ***Thermal stresses*** or ***Thermally induced stresses*** arise from a material or mechanical structure being acted upon by **temperature change** or **temperature gradient**.

- ✓ 3 sources for thermal stress
  - ✓ **Volumetric change**
  - ✓ **CTE mismatch**
  - ✓ **Thermal gradient**

Stresses in Welding: Volumetric change

- ✓ **Stresses induced by a volumetric change, either expansion or shrinkage, associated with some change of phase in the material of construction**
- ✓ Example: Material contracts after freezing except water, bismuth, and antimony.

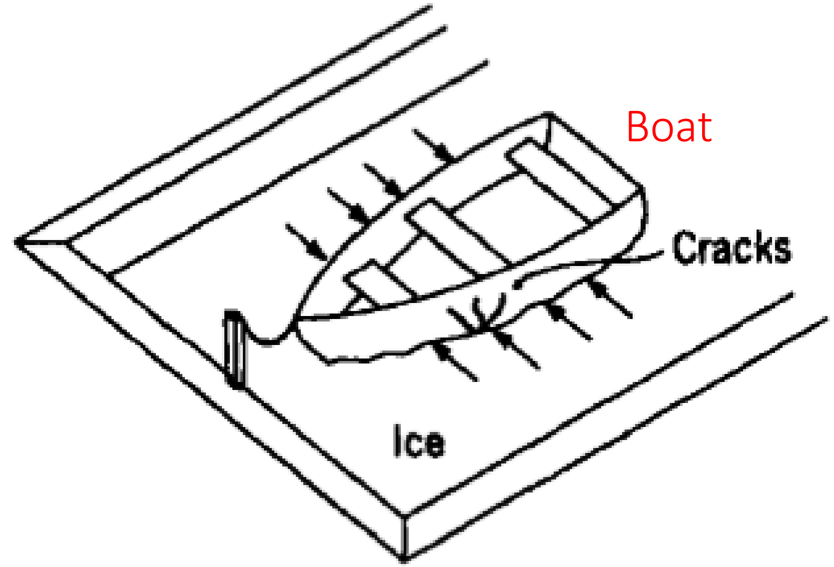


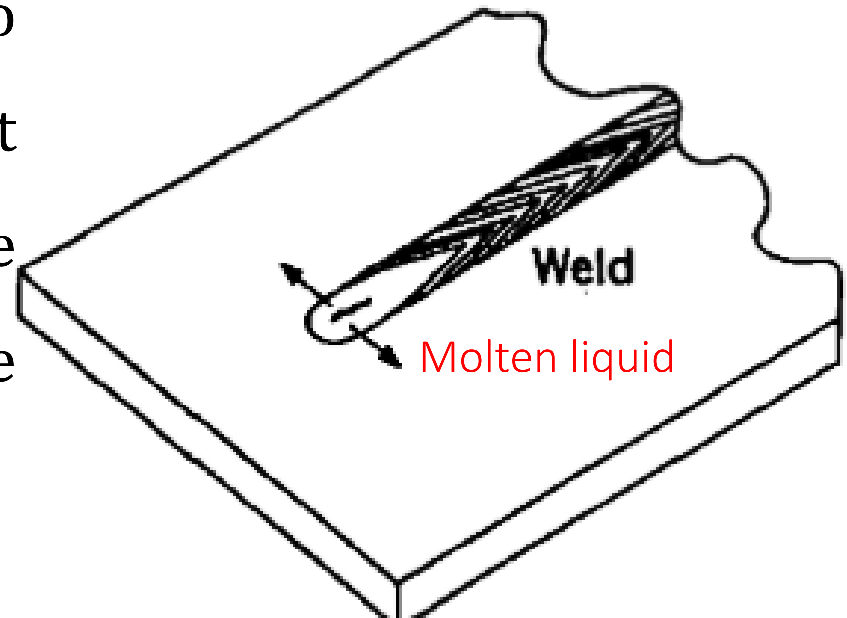


Stresses in Welding: Volumetric change

- ✓ Crushing of a wood- or fiberglass-hulled boat by ice formed in a lake.

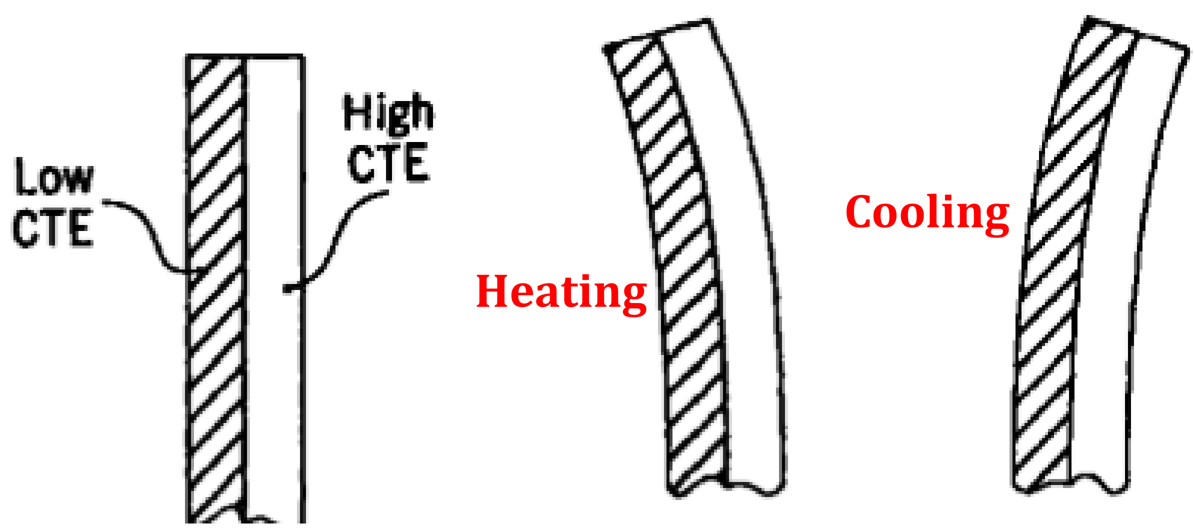
- ✓ In metal welding, liquid to solid metal shrinks: If free to move, the surrounding metal will move to accommodate the shrinkage. If not free to move, the solidifying volume of metal will either yield or fracture by cracking in tension.





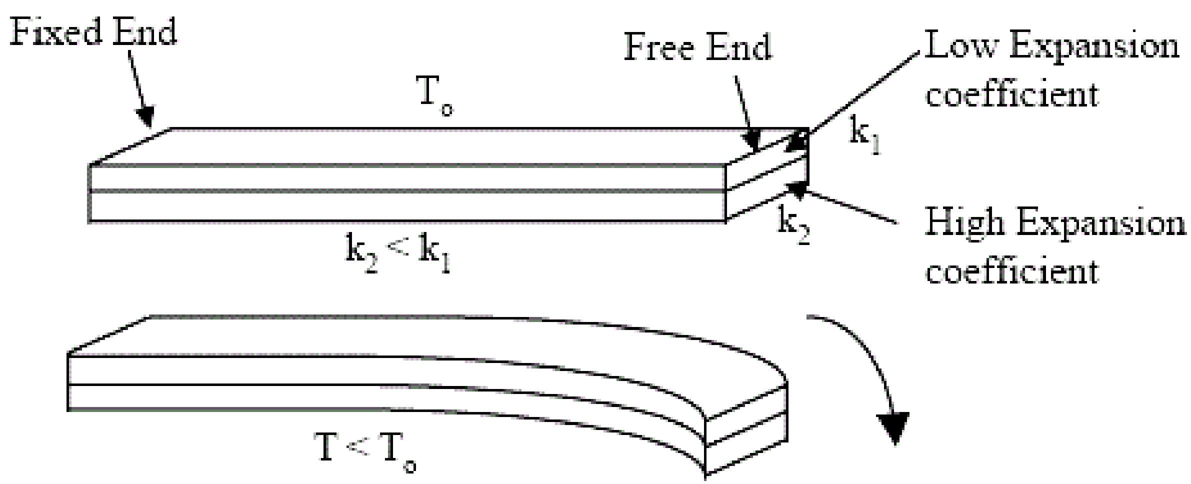
Stresses in Welding: CTE mismatch

- ✓ **Stresses induced by a difference in the Coefficient of Thermal Expansion (CTE) between two materials linked together, known as CTE mismatch**
- ✓ Example: An example of mismatched CTEs giving rise to a thermally induced stress is a bi-metal couple used in various temperature sensing/ indicative devices.



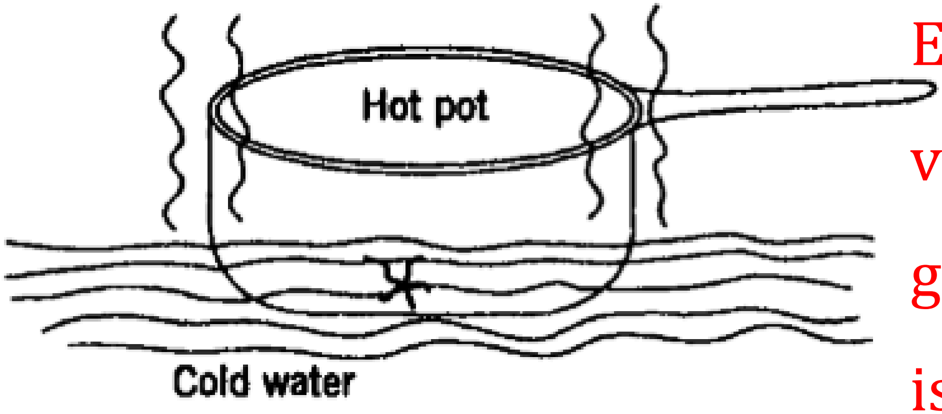
Stresses in Welding: CTE mismatch

- ✓ If a stripe of two metals with different CTE is joined along their length at some temperature, the material responds differently as the temperature changes from this point.
- ✓ During heating, higher CTE material causing bending of a straight two-layer strip toward the lower CTE material on heating.
- ✓ During cooling, lower CTE causes the bending of the straight two-layer strip towards the higher CTE.



Stresses in Welding: Thermal gradient

✓ Stresses induced by a temperature gradient resulting in differential rates of expansion or contraction within the volume of the material or within the structure.



Example: When a very hot, dry glass cooking pot is suddenly placed into cold water.

youtube.com/watch?v=avzyhROCCSI&ab_channel=mynameisjamesj

youtube.com/shorts/Yvb0XD6KshM?si=SQ24UA8R5UUGZXgZ

Stresses in Welding: Thermal gradient

- ✓ The outside of the walls and bottom of the pot cool faster than the inside. As a result, the outside contracts more than the inside.
- ✓ Due to this, outside layers of the pot's walls and bottom are in tension, causing a catastrophic fracture in such an inherently brittle material.
- ✓ A similar thing happens in any material or structure anytime there is a difference in temperature across any dimension, through the thickness, or along a length or width, although sometimes the material (or part) yields (usually by bending or buckling) only if it has sufficient ductility.

Stresses in Welding: Thermal gradient

https://www.youtube.com/watch?v=jQcF41QUHh4&ab_channel=jurek235

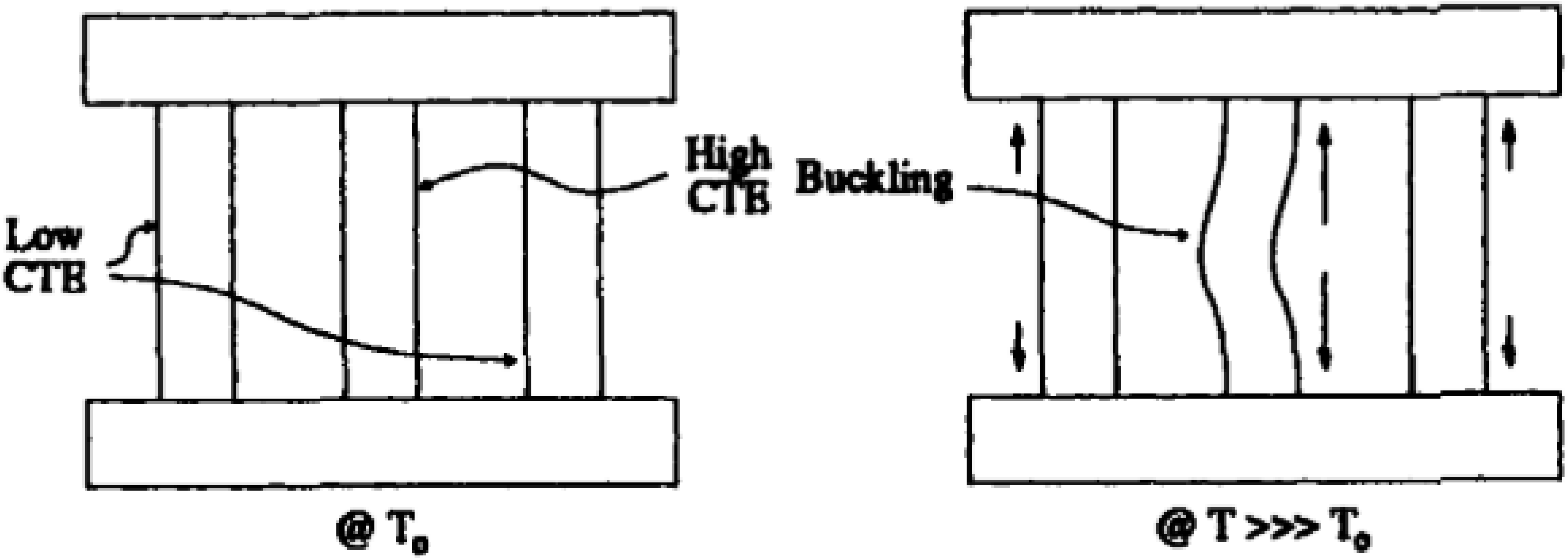
Distortion Versus Residual Stresses

- ✓ If thermally induced strains or stresses from one of the sources are unable to cause a material or structure to respond by distorting macroscopically.
- ✓ It will either cause it to deform microscopically (e.g., yield or crack) or result in stresses that (as opposed to being applied) are “locked in.”
- ✓ **Locked-in stresses are called residual stresses.**

Macroscopic distortion

- ✓ When stresses can cause macroscopic distortion, they will do so, and, in the process of causing this distortion, the thermally induced stresses are relieved, at least to below the yield stress, and, possibly, to lower levels due to creep.

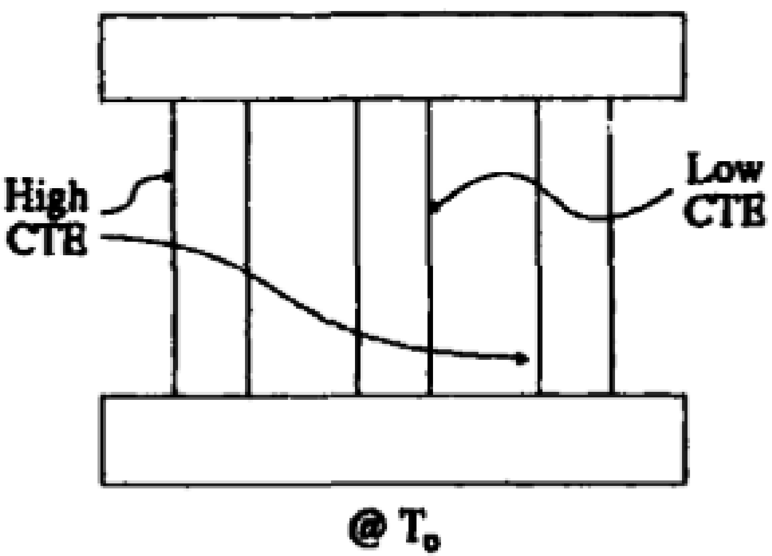
Macroscopic distortion

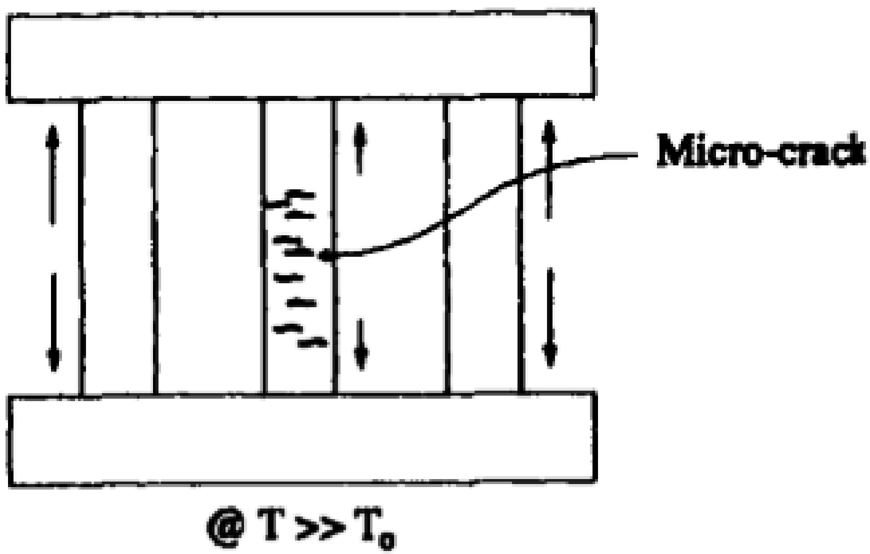


Microscopic distortion

✓ When stresses cannot cause macroscopic distortion, they either cause microscopic distortion or deformation (often in the form of cracking, but possibly, in the form of localized yielding) to relieve themselves, or they are locked in to become residual stresses.

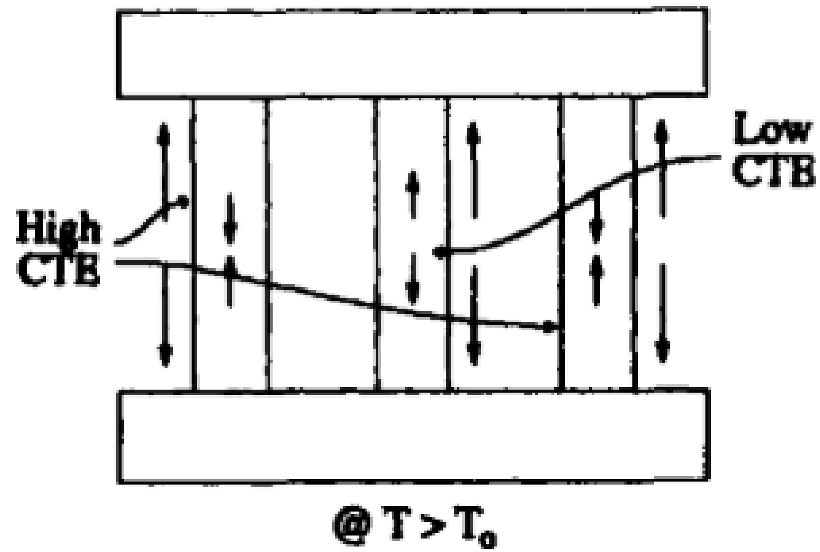
Microscopic distortion





Residual Stresses

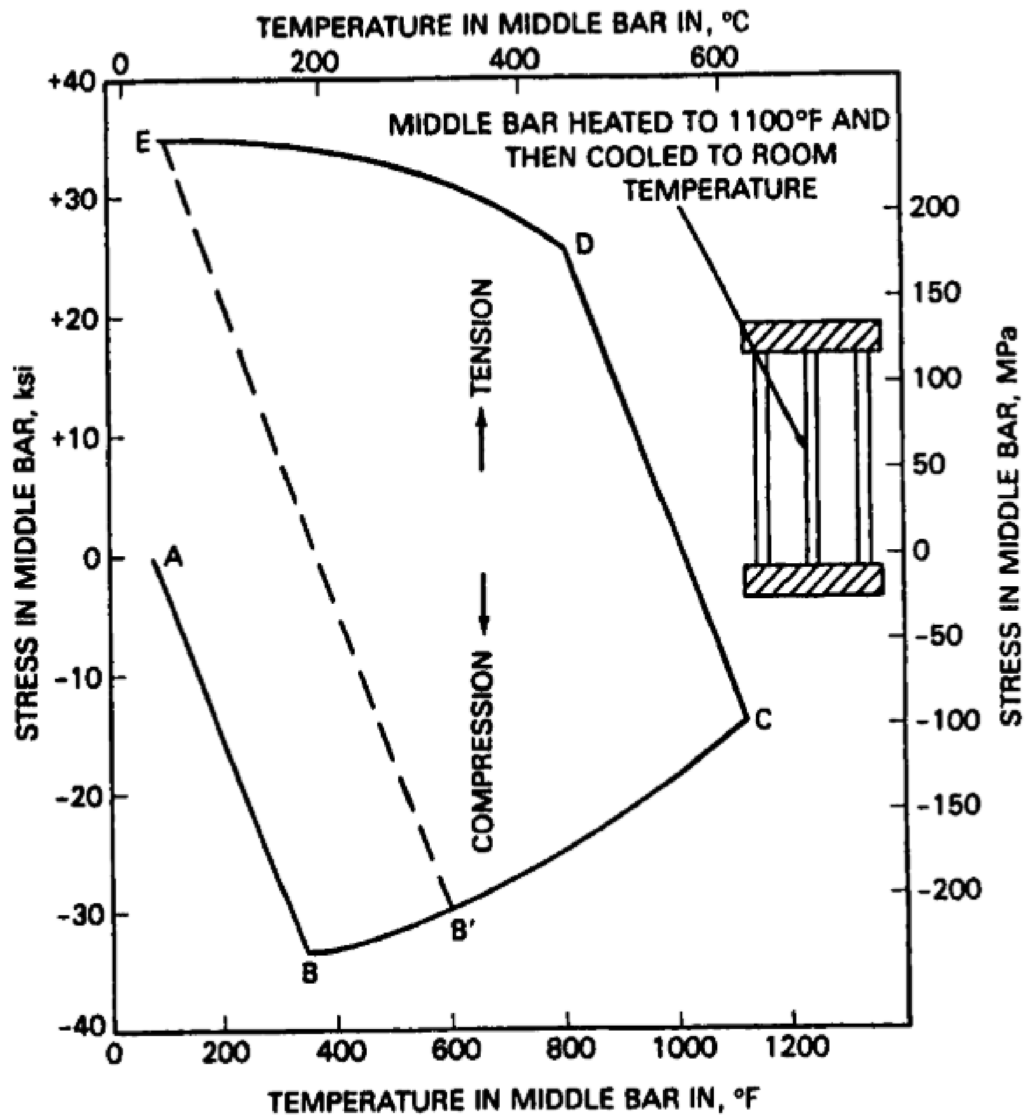
✓ In this last case, thermally induced stresses are not relieved, they are locked in!



✓ Not surprisingly, locked-in or residual stresses have rarely good consequences, the exception being where compressive residual stresses can be induced to offset at least the initial levels of applied tensile stresses, as in prestressed cement or concrete or thermally or chemically tempered glass.

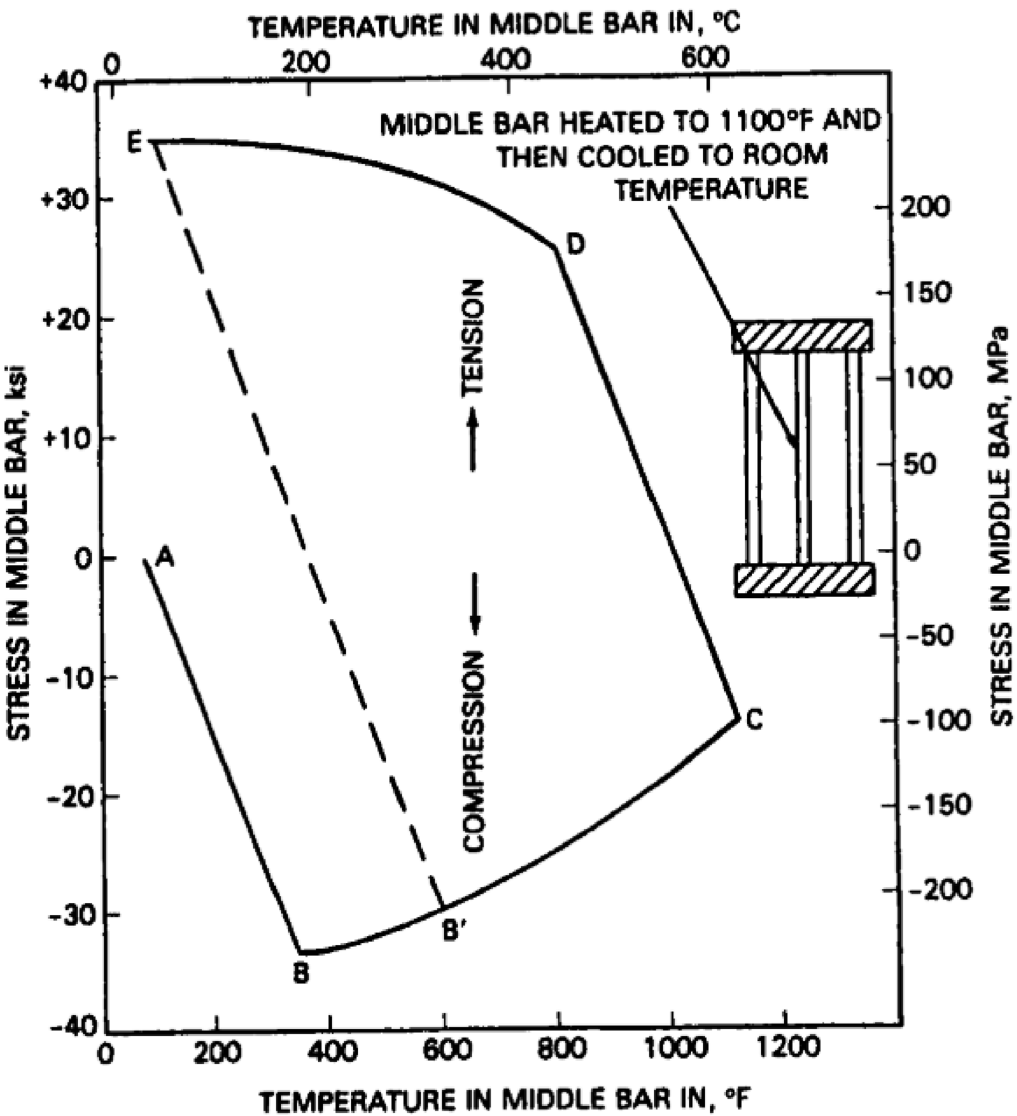
Three Bars arrangement

- ✓ Stress in welding can be explained by the analogous situation that exists in weldment by three bar arrangement.
- ✓ Three bars of carbon steel, having the same length and cross-sectional area, are connected at their ends by two rigid cap members.



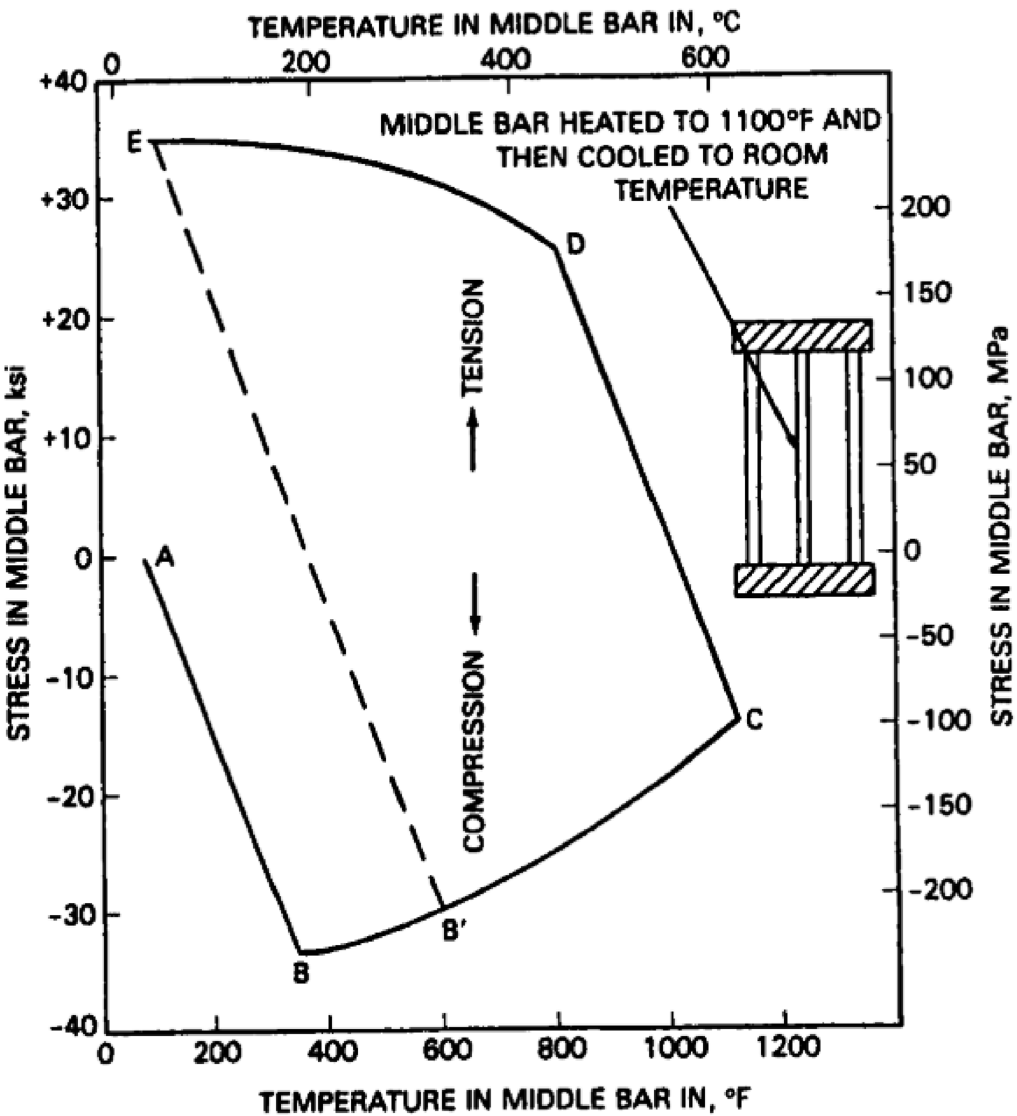
Three Bars arrangement

- ✓ If the end horizontal members and middle bar are heated to 595°C (1100°F) and cooled to room temperature.
- ✓ Two outside bars are kept constant at room temperature.



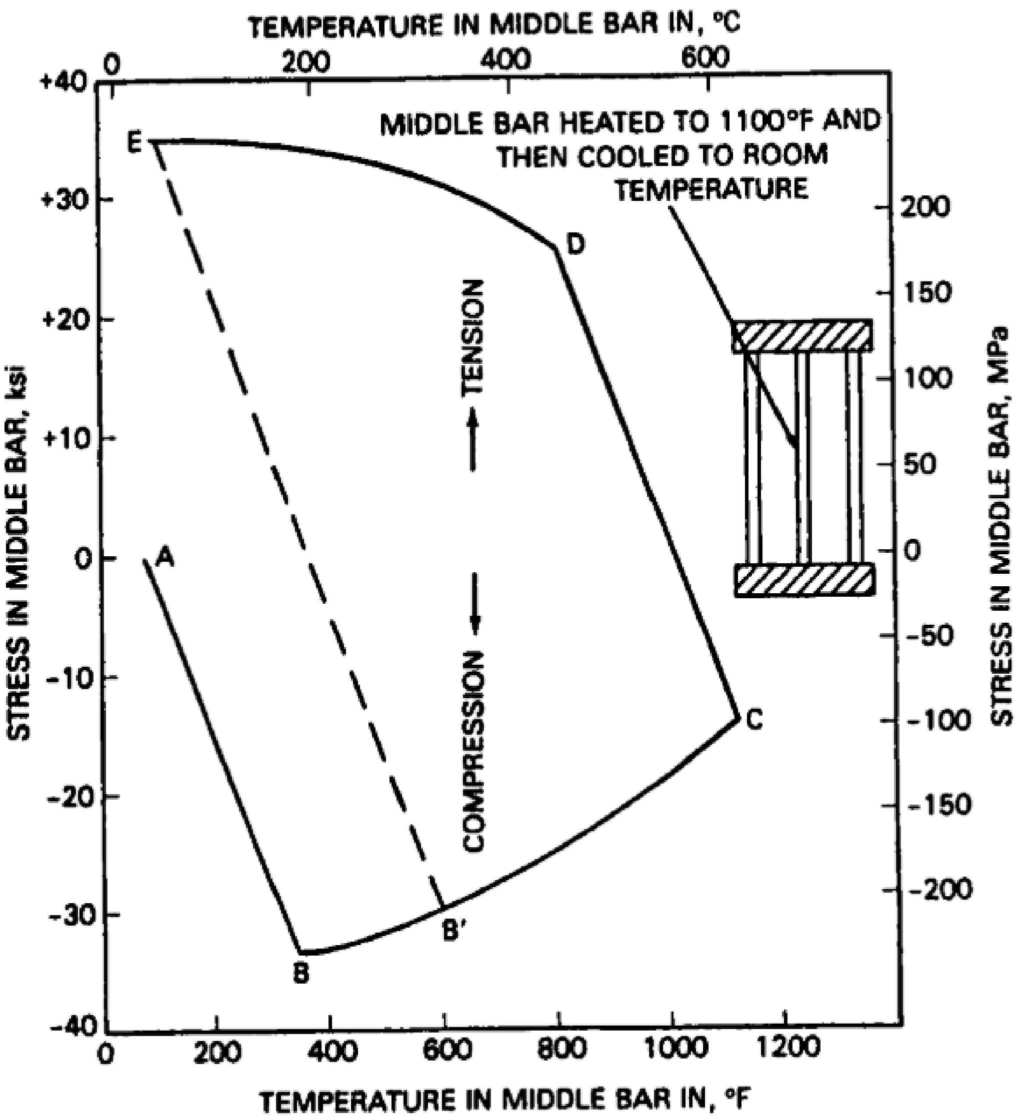
Three Bars arrangement

- ✓ When the bar is heated compressive stresses arise in it because its expansion is restrained by the outside bars.
- ✓ Stresses produced in the outside bars are residual stresses.
- ✓ The two outside bars resist the deformation of the middle bar.



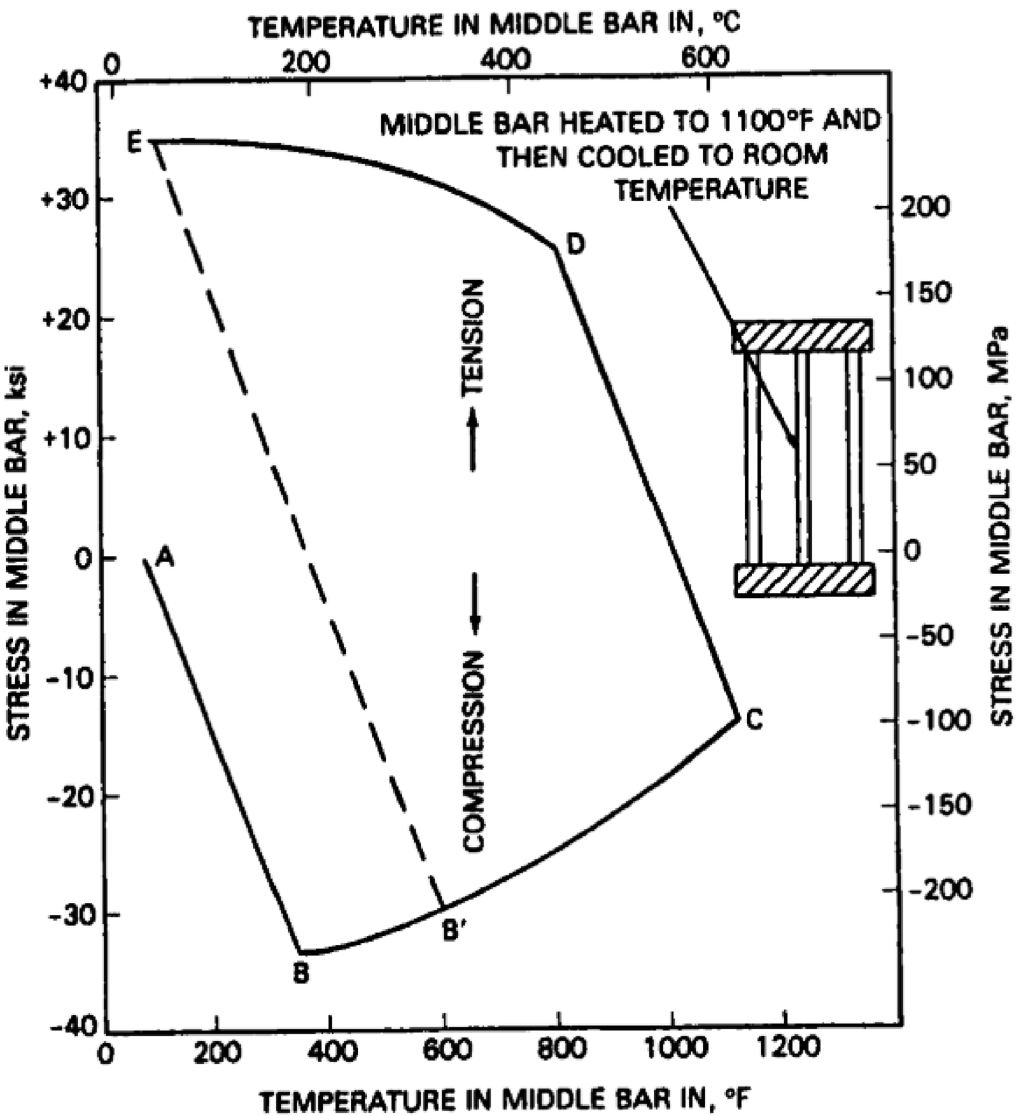
Three Bars arrangement

- ✓ The stress in each outside bar is half the value of the stress in the middle bar, but of opposite sign or type,
- ✓ As the temperature of the middle bar increases, the magnitude of the compressive stress that arises along a “line AB.”

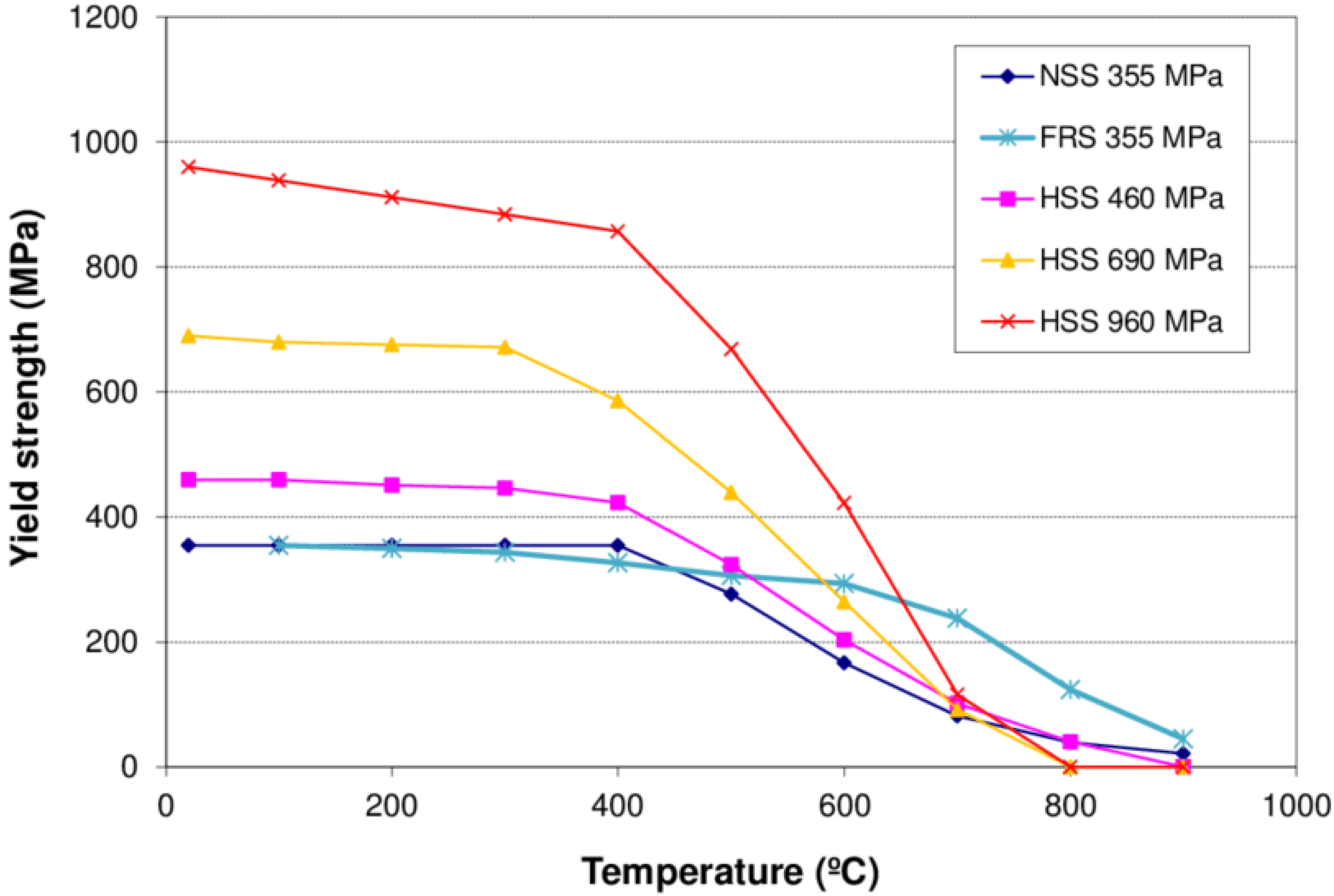


Three Bars arrangement

- ✓ As the compressive yield point is reached (point B= 170°C or 340°F), the stress in the bar decreases with temperature, as shown by "line BC."



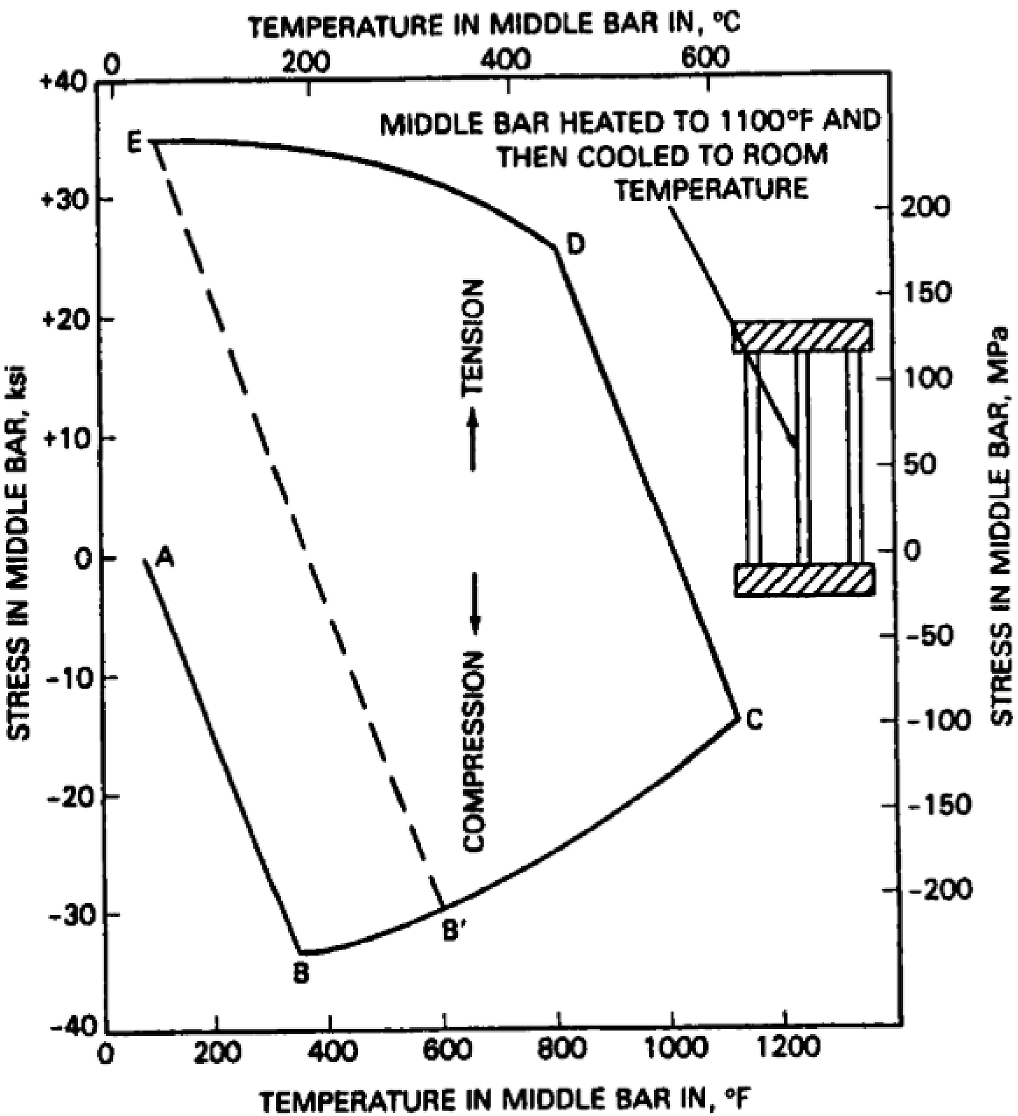
Three Bars arrangement



Three Bars arrangement

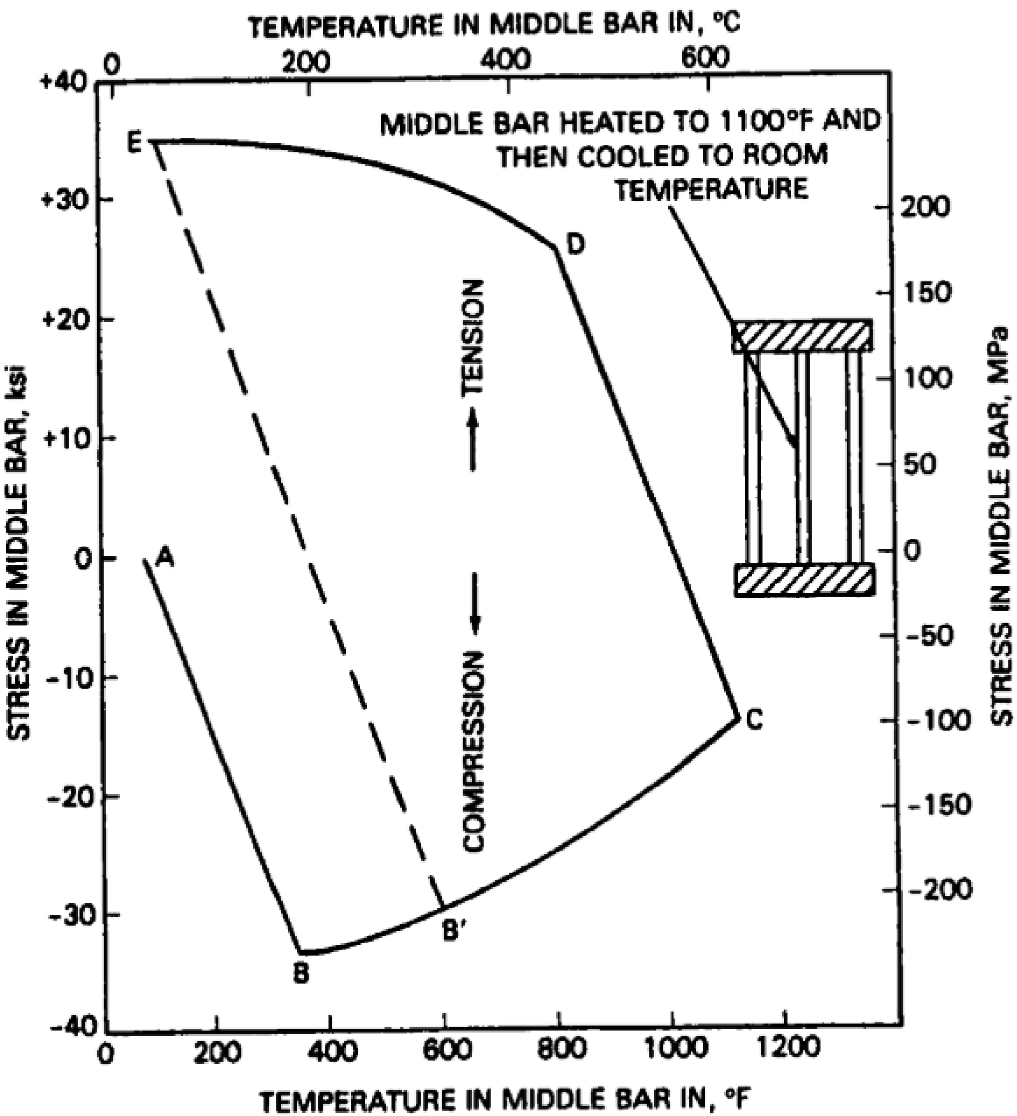
- ✓ As the temperature increases beyond 170°C, the stress in the middle bar is limited to the yield strength, which decreases with increasing temperature as shown by curve BC.

- ✓ At point C: heating is stopped: 595°C (1100°F)



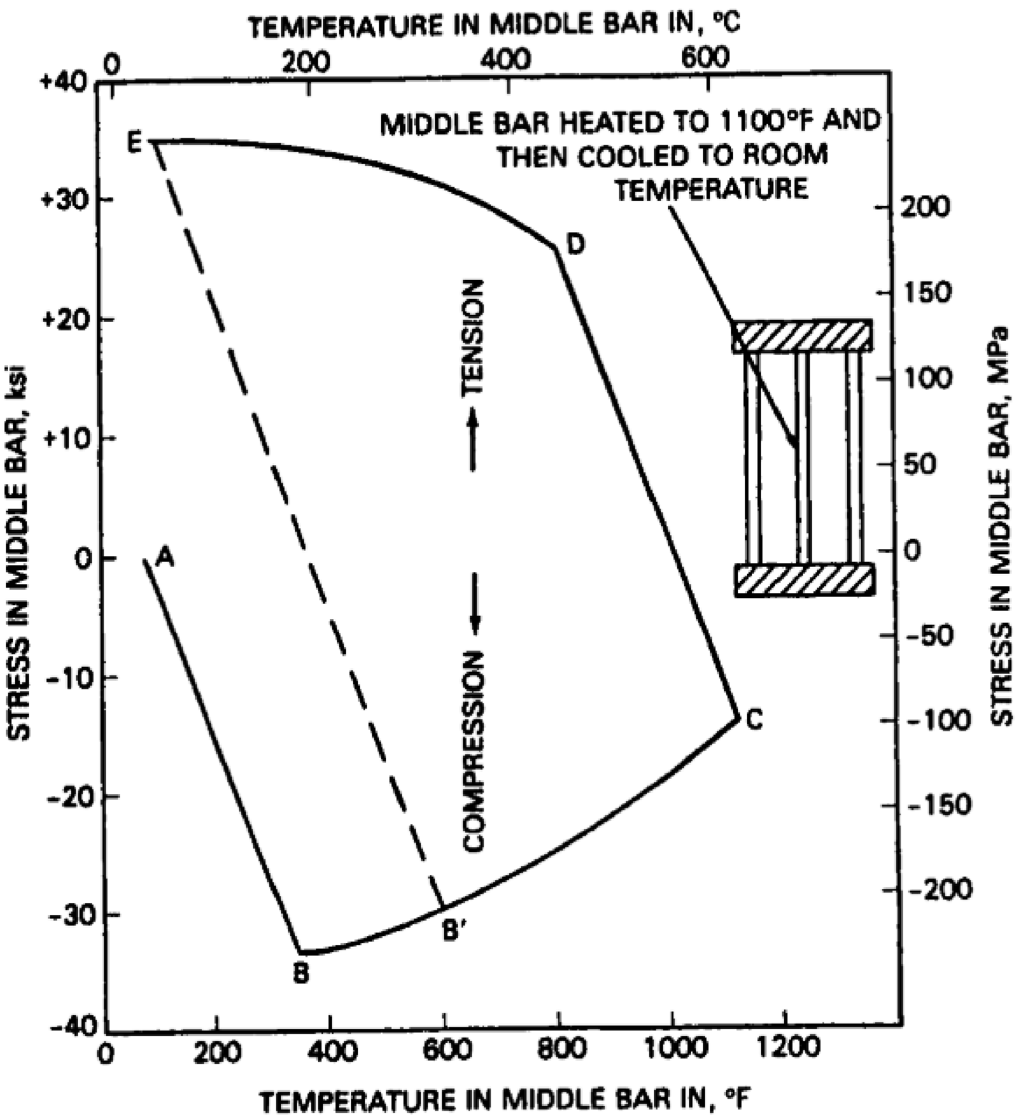
Three Bars arrangement

- ✓ After point C: Cooling starts
- ✓ As temperature decreases from point C, middle bar cools and the response of the middle bar is elastic.
- ✓ Stress drops rapidly
- ✓ At some point, stresses change from compression to tension.



Three Bars arrangement

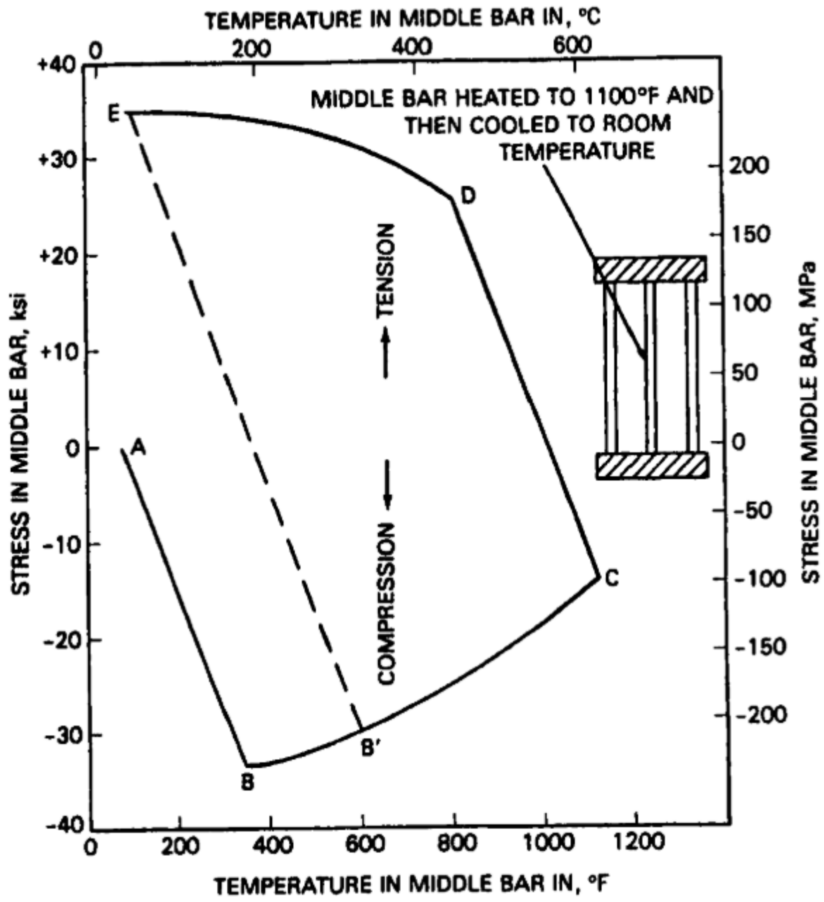
- ✓ Tension increases till the yield strength of the bar reaches D (“line CD”).
- ✓ As temperature decreases, further stresses in the middle bar are limited by its yield strength, as shown by “curve DE.”



Three Bars arrangement

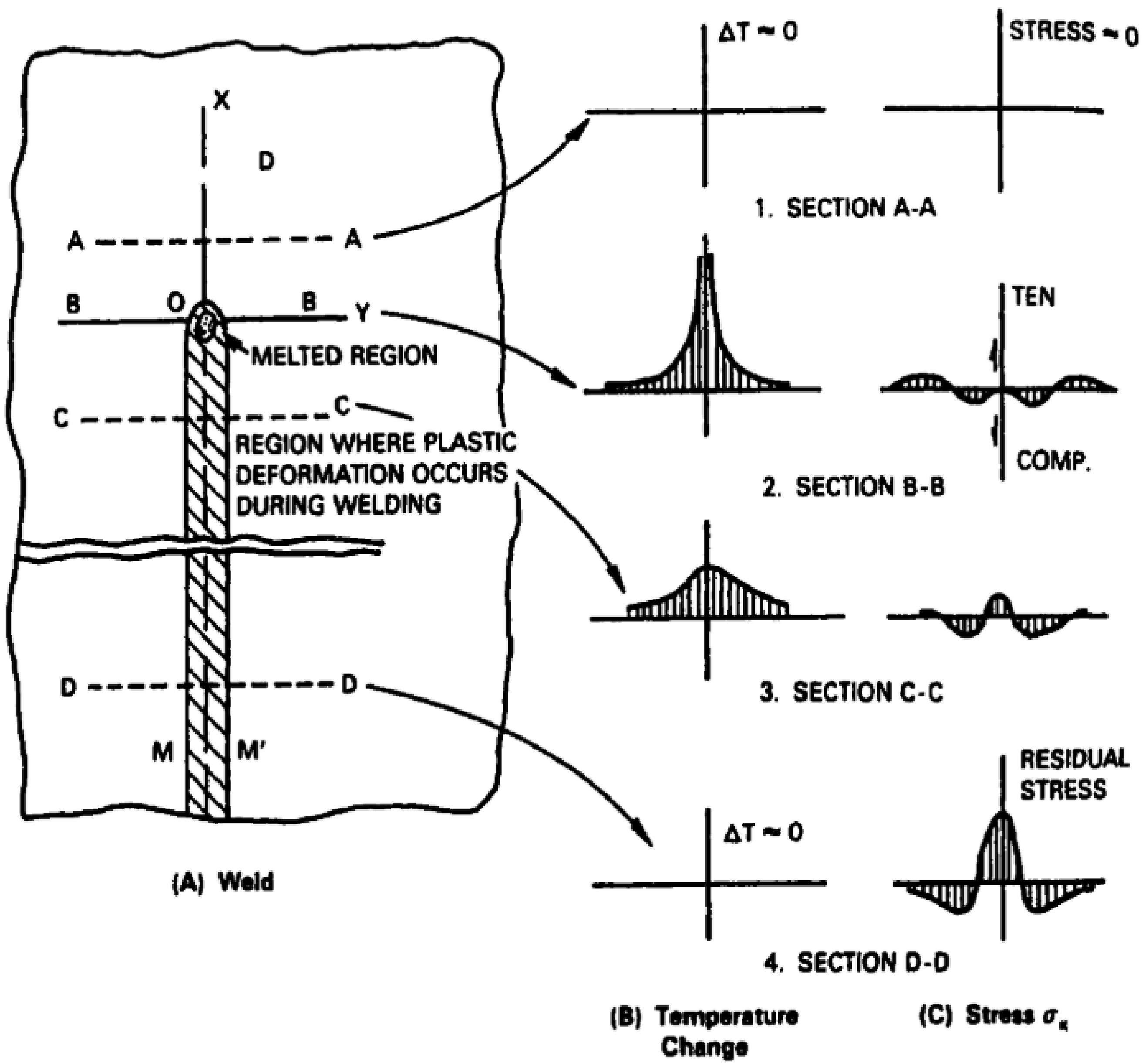
- ✓ A residual stress, equal to the yield strength in tension, is set up in the middle bar.

- ✓ **Residual compressive stresses** of half this value are set up in each outside bar to balance the system mechanically.



Typical Residual Stresses in Weldments

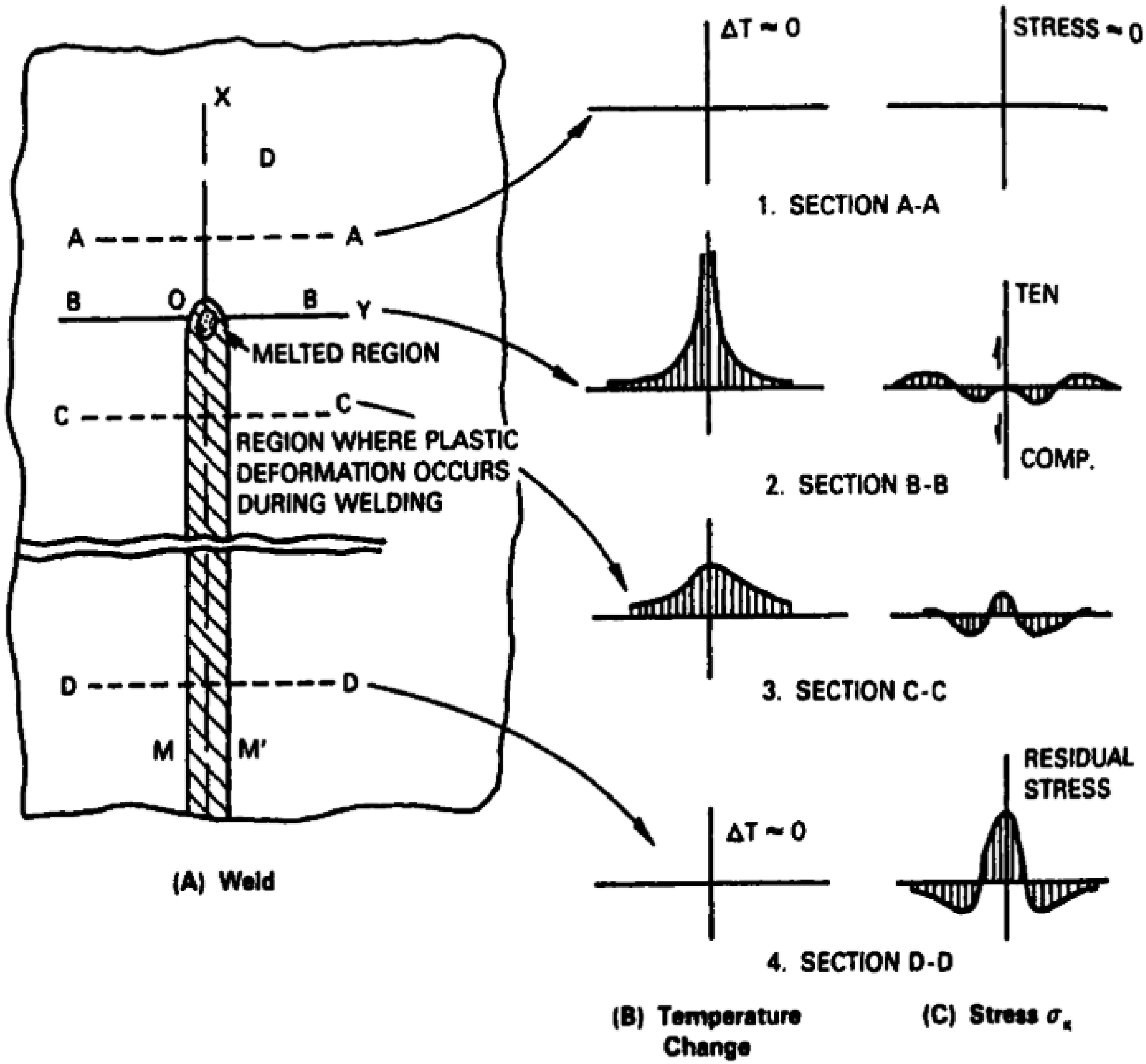
- ✓ **A-A Section**: ahead of the source where ΔT is essentially zero: is not affected by the heat input therefore, σ_x is zero.



Typical Residual Stresses in Weldments

Typical Residual Stresses in Weldments

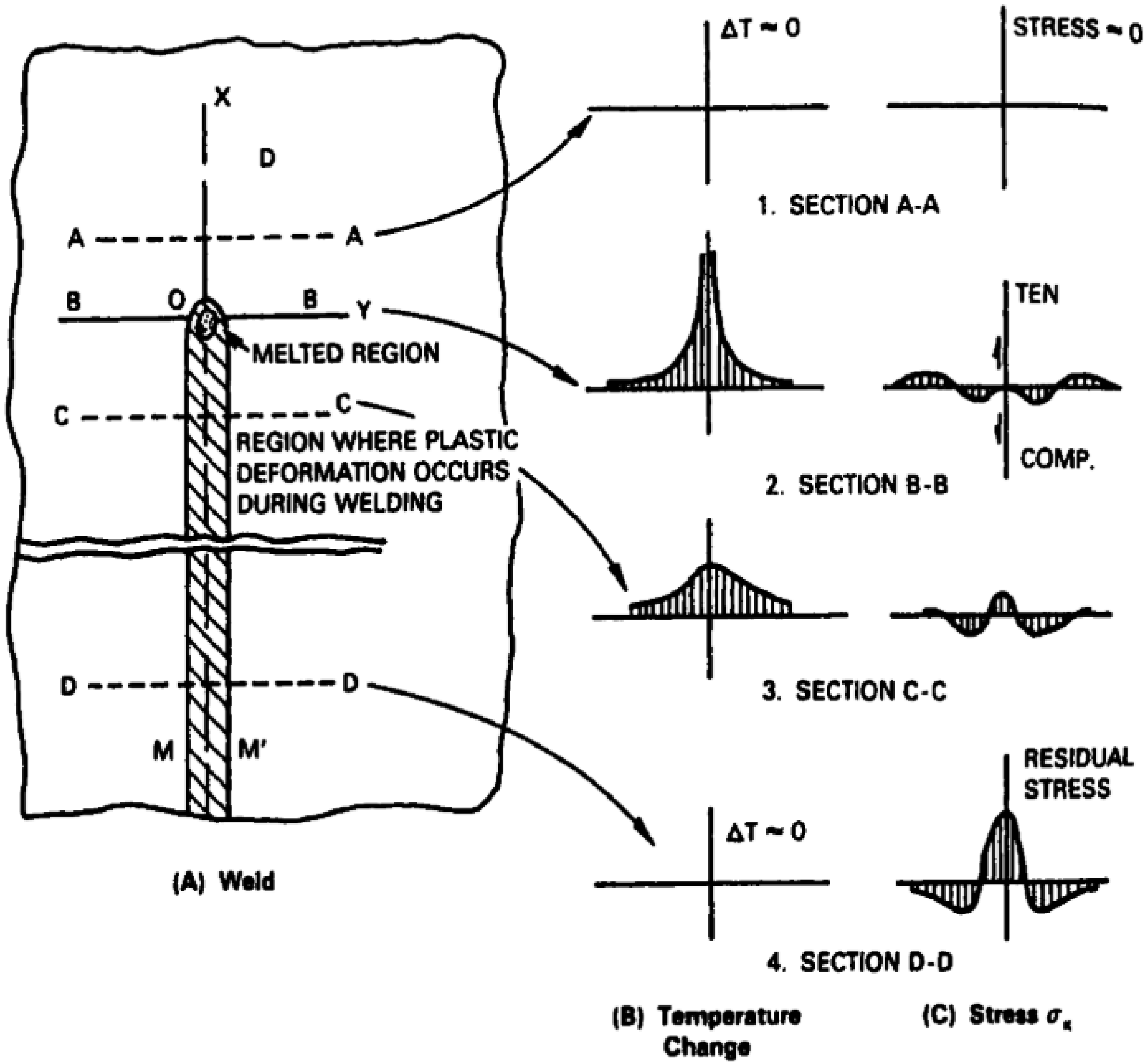
- ✓ **B-B section:** intersect the heat source, the temperature distribution is steep: σ_x is close to zero in the region underneath the heat source. In the region away from the heat source, stresses are compressive (σ_x is negative) due to the expansion of these areas restricted by the surrounding metal.



Typical Residual Stresses in Weldments

Typical Residual Stresses in Weldments

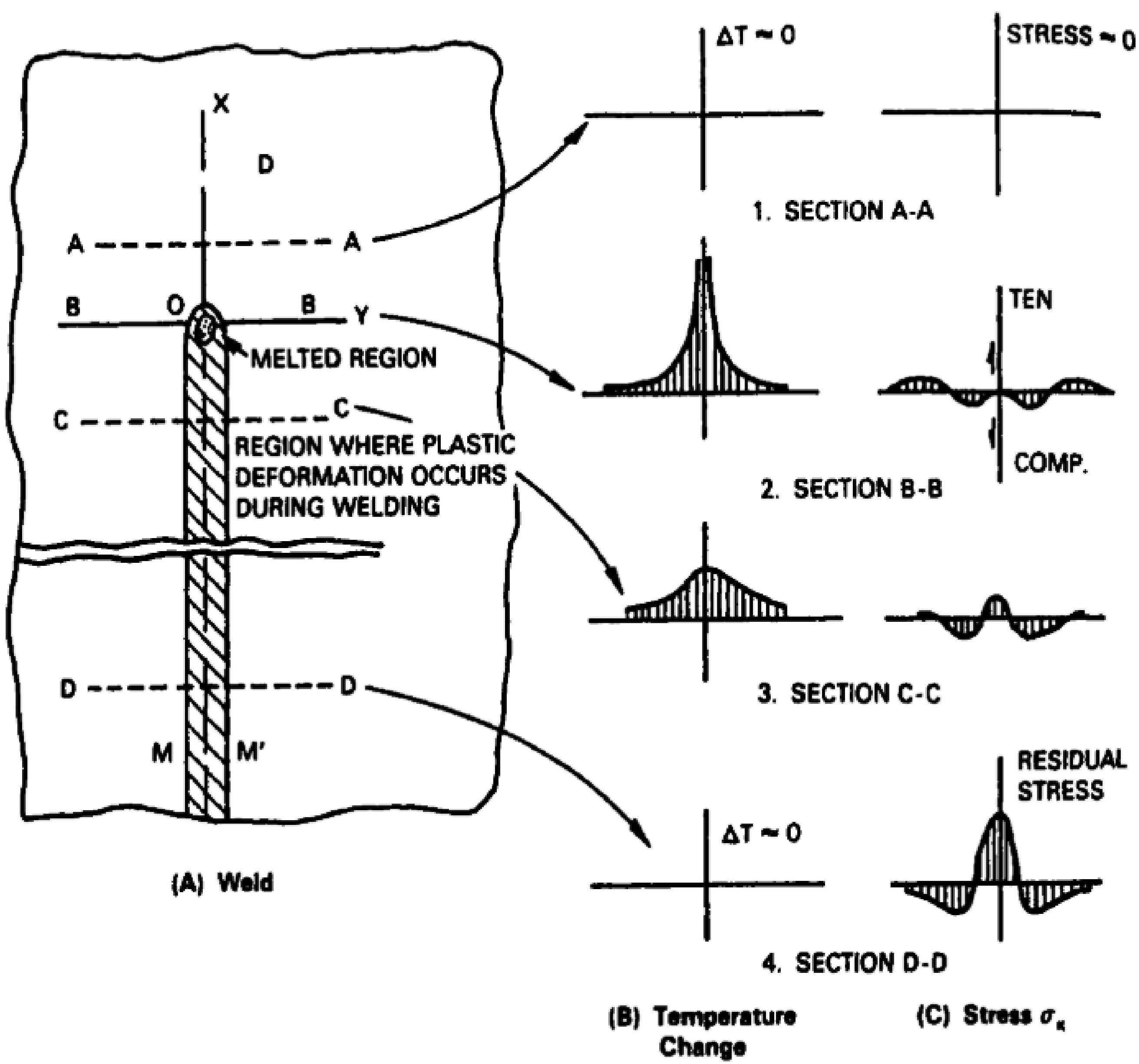
- ✓ **C-C section:** Behind the heat source, the temperature distribution is less steep: Weld metal contracts due to cooling, thus producing tensile stresses (σ_x is positive). In nearby areas σ_x is negative.



Typical Residual Stresses in Weldments

Typical Residual Stresses in Weldments

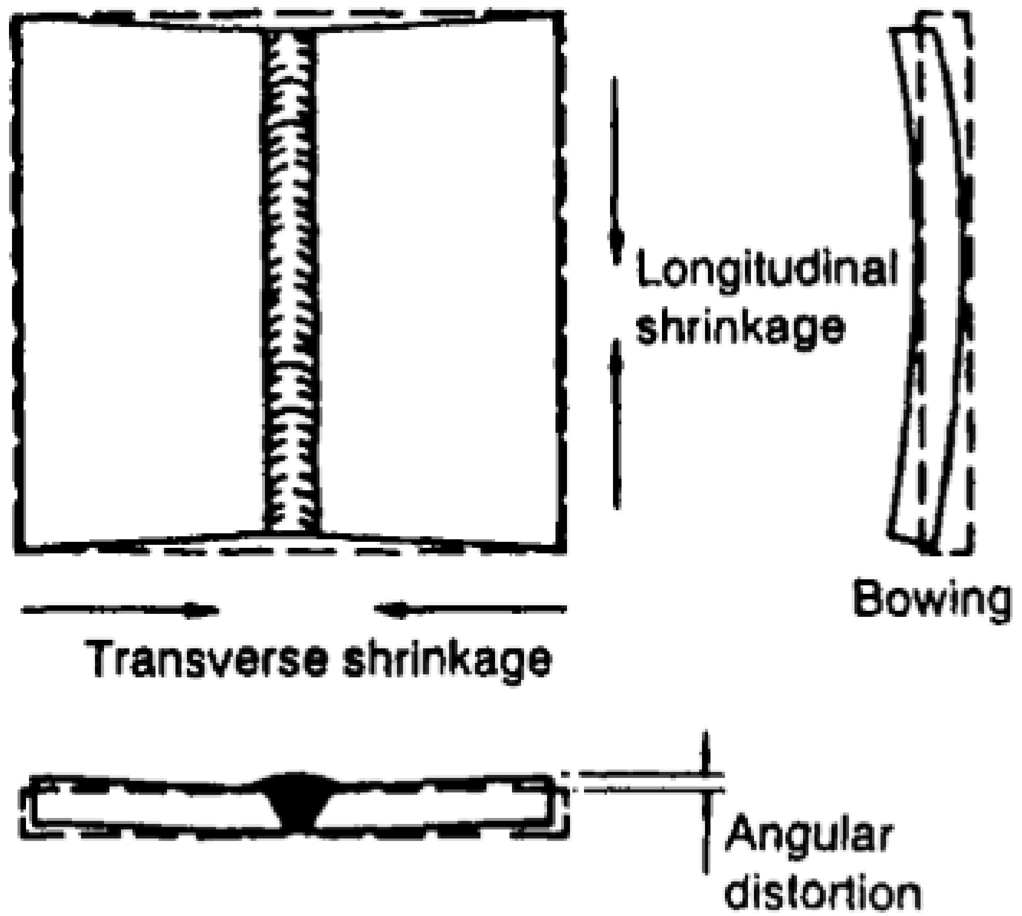
- ✓ **D-D section:** far behind from the heat source, the temperature distribution is eventually uniform: Weld metal contracts further, thus producing higher tensile stress in the region near the weld and compressive away from the weld.



Typical Residual Stresses in Weldments

Distortion in Weldments

- ✓ Three fundamental dimensional changes taking place during welding can cause distortion
  - ✓ **Transverse shrinkage that occurs perpendicular to the weld line**
  - ✓ **Longitudinal shrinkage that occurs parallel to the weld line**
  - ✓ **Any angular change that consists of rotation that occurs around the weld line**



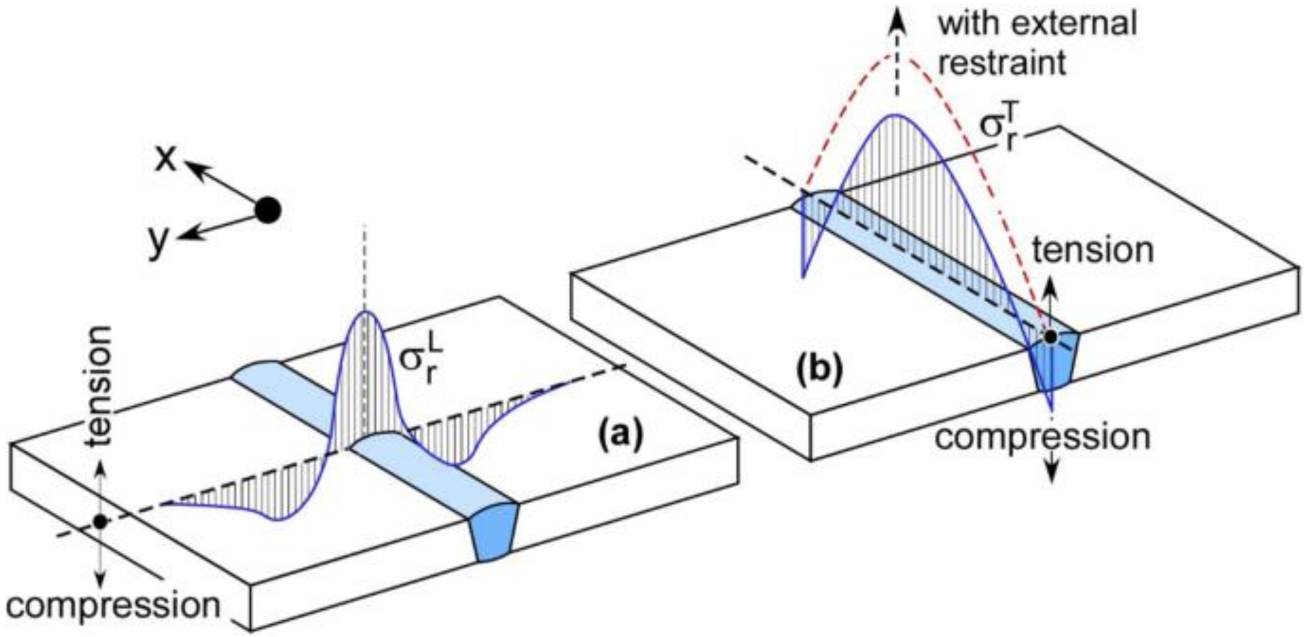
Residual Stresses in Butt Weldments

According to Masubuchi and Martin (1961), the distribution of longitudinal residual stress (σ_x) can be approximated by

$$\sigma_y(x) = \sigma_m \left[1 - \left(\frac{x}{w}\right)^2\right] e^{-\frac{1}{2}\left(\frac{x}{w}\right)^2}$$

where σ_m is the maximum residual stress, which usually reaches no more than the yield strength of the base metal.

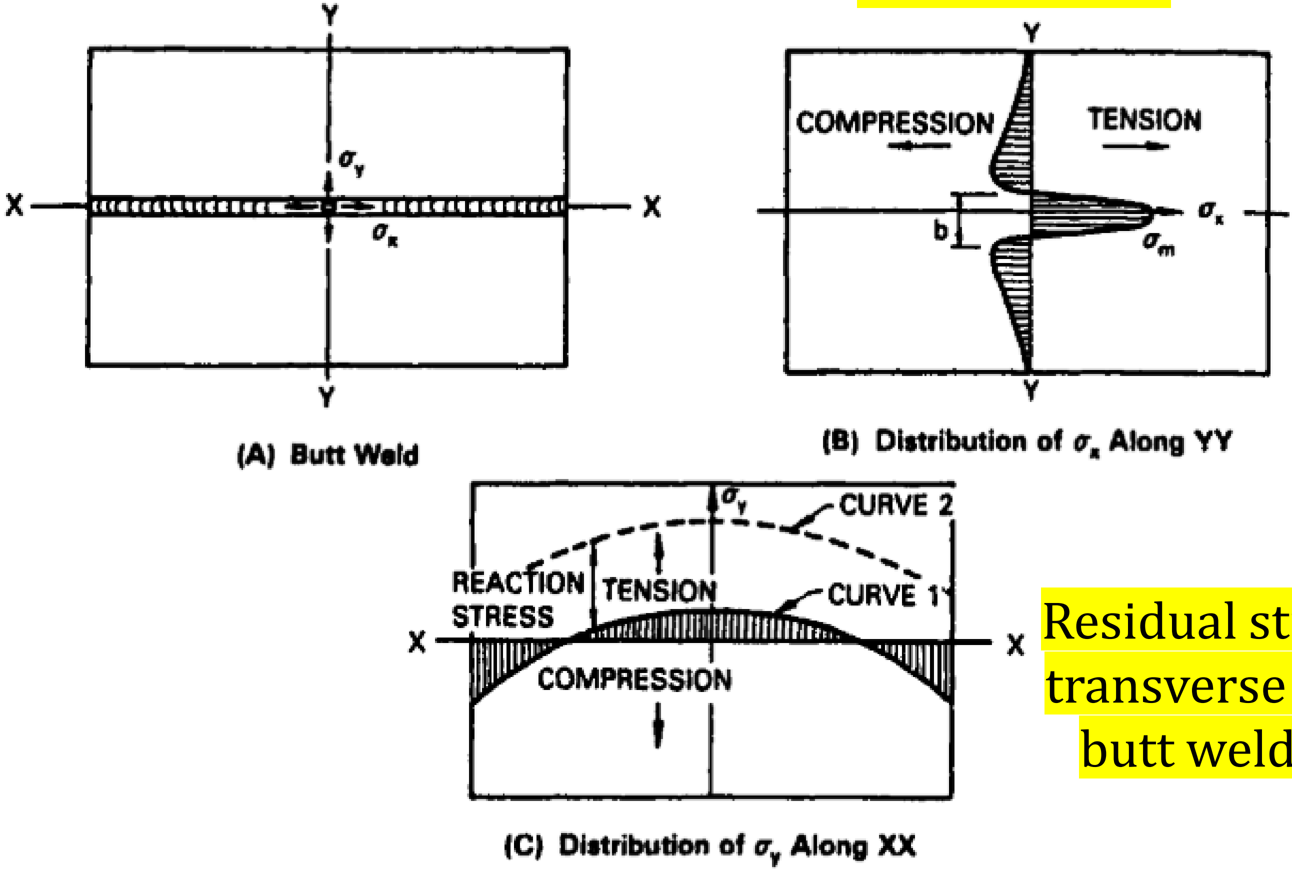
The parameter w is the width of the tension zone of σ_x.



Residual Stresses in Butt Weldments

Butt weld line

Residual stresses longitudinal to the butt weld line



(A) Butt Weld

(B) Distribution of σ_x Along YY

(C) Distribution of σ_y Along XX

Residual stresses transverse to the butt weld line