Lecture 42:

Physical metallurgy of metal joining (welding)

Questions:

1. Why there is excessive grain growth in the heat affected zone of a welded structure even if it is made of micro alloyed steel?
2. Most structural steels have some amount Mn primarily to take care of the hot shortness problem because of residual sulfur in steel. Some amount of Si is also present. It is added to remove dissolved oxygen in steel. ASTM A516 Grade 60 is a common grade of steel used for the construction of welded vessels. It has 021C, 0.66Mn, 0.45Si, S <0.035, P < 0.035. Examine if it is suitable for construction of welded pressure vessel.
3. What are the precautions that need to be taken to weld creep resistant steel tubes having 0.15C, o.5Mn, 0.54Si, 2.25Cr, 1.0Mo (this corresponds to ASTM T 22 grade steel)?
4. There is no chance of forming martensite in heat affected zone while welding austenitic steel. Should therefore all grades of austenitic steels be easily weldable? Give reasons for your answer.
5. Derive an expression for the time it takes to reach maximum temperature at a distance r from the heat source during arc welding of a thick plate. Estimate maximum temperature at a point 5mm away from the heat source during welding of carbon steel. Material and process parameters are as follows: thermal conductivity = 50W/m/K, density = 7850kg/m3, specific heat = 0.45kJ/kgK, initial temperature of the plate = 300K, weld current = 150 A, voltage = 20volts, welding speed = 2.5mm/s, heat lost = 0.4.
6. Use the data given in problem 5 to estimate the distance at which temperature would reach 1500^oK (the melting point of the steel).

Answers:

1. Micro-alloy elements are present in steel as carbo-nitrides. These are effective in pinning grain boundaries during normal thermo-mechanical processing. However during welding temperature near fusion zone goes beyond their solvus temperature. Absence of precipitates to pin austenite boundaries in this region leads to excessive grain growth.

2. Medium carbon steels are more prone to heat affect zone related problem. Although % C is 0.21 its carbon equivalent = 0.21+0.66/6 = 0.33. This too is less than 0.4% C. Therefore it can be welded without any special precaution. There is little chance of formation of hard and brittle martensite from where crack could initiate. Experience shows that failures often do not take place in the main welds of a structure rather it initiates from points where a small weld bead may have been placed to attach ancillary equipments temporarily during fabrication.

3. Carbon equivalent for this steel = 0.15 + 0.54/6 + (2.25+1.0)/5 = 0.89. In this case martensite is likely to form unless special precautions are taken to preheat the tubes before

welding. This would help reduce cooling rate encountered in the HAZ during welding. In many cases post weld heat treatment is also required. Note that most steel specifications allow a range of composition. To decide whether any special precaution is necessary carbon equivalent should be estimated using the maximum permissible alloy content.

4. Totally different kinds of problem are faced during welding of austenitic steel. One is related to solidification shrinkage which is much more than in ferritic steel. This is overcome by suitable control of the composition of weld consumables so that on solidification it has some amount of delta ferrite. Ferrite meters, a non destructive testing tool to detect if there is some delta ferrite. The second problem is associated with the precipitation of $Cr_{23}C_6$ at grain boundaries in the heat affected zone. The carbides have very high amount of chromium. Whenever such precipitates are formed chromium content of the surrounding matrix drops below the minimum amount needed to form protective oxide layer. These regions become prone to corrosive attack. Often it leads to inter granular failure. This phenomenon is known as sensitization. Stainless characteristics of sensitized steel can be restored by giving post weld annealing by heating to 950˚C followed by rapid cooling to suppress carbide precipitation. Alternatively select special low carbon austentic steels or those having additional alloy elements like Nb. This is a strong carbide forming element. It does not allow any carbon to be present in the matrix to form $Cr_{23}C_6$.

5. Temperature at distance r from a moving point heat source is given by the following expression: $T = T_0 + \frac{q}{2\pi\lambda vt} exp\left(-\frac{r^2}{\alpha t}\right)$ where T is temperature, t is time, α is thermal diffusivity, v is welding speed, λ is thermal conductivity, T_0 is initial temperature of the plate, q =εiV where i = current, V = voltage, ε = efficiency, $\alpha = \lambda/(\rho c)$ where ρ = density and c = specific heat. To find out time at which T reaches maximum at a given point r equate: $\frac{dT}{dt} = 0 = \frac{dln(T-T_0)}{dt}$. Since $ln(T - T_0) = ln\left(\frac{q}{2\pi\lambda v}\right) - ln(t) - \frac{r^2}{\alpha t}$ or $\frac{1}{(T-T_0)}\frac{dT}{dt} = \left(\frac{r^2}{\alpha t^2} - \frac{1}{t}\right) = 0 \therefore t_{max} = \frac{r^2}{\alpha}$ On substituting this in the expression for T: $T_{max} = T_0 + \frac{q}{2\pi\lambda vet_{max}}$ On substituting numerical values one directly gets both t_{max} and T_{max}. $t_{max} = \frac{r^2}{\lambda}\rho c = \frac{(0.005)^2}{50} \times 7850 \times 450 = 1.77\ second$ and $T_{max} = T_0 + \frac{q}{2\pi\lambda evt_{max}} = 300 + \frac{0.6\times150\times20}{2\pi\times50\times0.0025\times1.8\times2.718} = 777^0K.$

6. The expression for T_{max} can be rewritten as $T_{max} = T_0 + \frac{\varepsilon iV\alpha}{2\pi\lambda evr^2}\ or\ r^2 = \varepsilon iv\alpha/\{2\pi\lambda ev(T_{max} - T_0)\}$ = $(0.6 \times 150 \times 20 \times 1.42 \times 10^{-5})/(2\pi \times 50 \times 2.718 \times 0.0025 \times 1200) = 0.00316m$