CHAPTER 3

Analytical modeling for heat generation rate in of FRICTION WELDING OF TUBE TO TUBE PLATE WITH AN EXTERNAL TOOL (FWTPET)

3.1 Heat Generation

Heat generation in case of friction welding is depends on the contact condition between tool shoulder and tube plate, mechanical interaction due to velocity difference between stationary work piece and rotating tool produces heat by friction work & material deformation.

In this process tool pin will not contribute for heat generation as it is not in contact with work piece for clearance fit method. So Q=0, so total heat generated is form tool shoulder only. Defining of contact condition is a critical part of numerical modeling. But in this process only sliding contact exist between tool shoulder and work piece.

Numerical model for heat generation is developed on the basis of Coulombs law of friction which describe the relation between shear force between tool surface and work piece matrix.

$$\tau_{friction} = \mu \cdot P \quad \left({}^{N}/_{mm^2}\right)$$

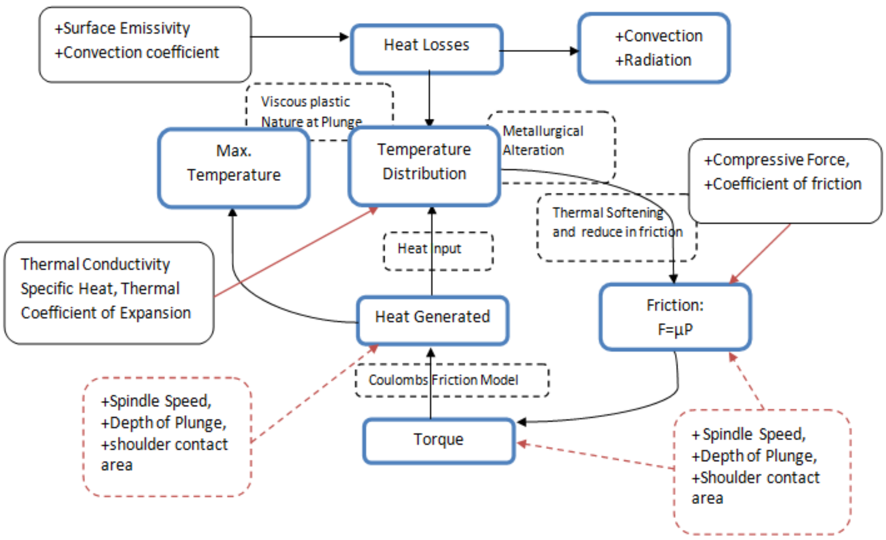

Fig. 3.1 Schematic flow diagram of dependent and independent process parameters

General Equation for heat generation: An element is considered on tool shoulder surface at radius ‘r’ and of radial thickness ‘dr’.

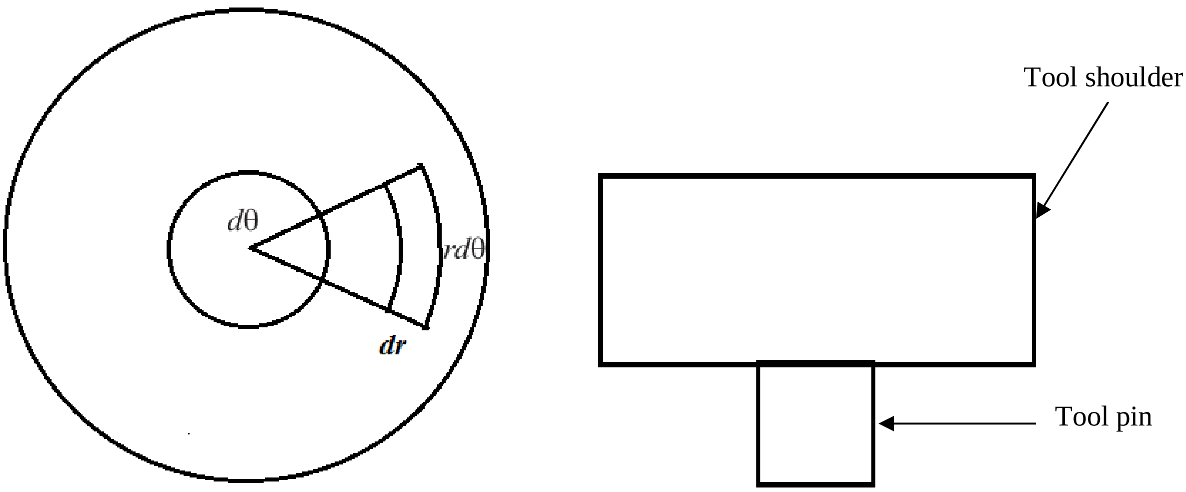

Fig. 3.2 Schematic drawings (a) horizontal surface (b) Vertical

Part of heat generated by small segment

$$dQ = w\ dM$$

$$dQ = w\ (rdF)$$

But $dF = \tau_{friction} dA$ so

$$dQ = w\ r\ (\tau_{friction} dA)$$

But Segment area $dA = r\ d\theta\ dr$

$$dQ = w\ r\ (\tau_{friction}\ r\ d\theta\ dr)$$

$$dQ = w\ r^2 \tau_{friction}\ d\theta\ dr$$

This is the general Heat generation equation for circular surface with radius ‘r’

Heat Generation from shoulder:

Tool shoulder only responsible for total heat generation in clearance fit method of FWTPET, Shoulder with Outer radius Ro ,Actual Contact Area is not shoulder area as total clearance provided is ‘c’ so Contact area of Radius range is from ‘Ri’ to ‘Ro, where Ri is internal radius of tube , and shoulder internal radius is ‘ Ri – c ‘

$$Shoulder\ radius = R_i - c$$

Equation for Total heat generated from shoulder is derived by integrating the general equation for heat generation.

$$\dot{Q}_T = \int_{0}^{2\pi} \int_{R_i}^{R_O} w\, r^2\, \tau_{friction}\, d\theta\, dr$$

Integrating with radius from limit R_i to R_o

$$\dot{Q}_T = \int_0^{2\pi} w\;\; \tau_{friction}\, d\theta\, \left[\frac{r^3}{3}\right]_{R_i}^{Ro}$$

$$\dot{Q}_T = \int_0^{2\pi} \frac{w\,(R_O^3 - R_i^3)}{3} \tau_{friction}\, d\theta$$

$$\dot{Q}_T = \frac{2\pi}{3} w\, \tau_{friction}\, (R_O^3 - R_i^3)$$

This is the equation for total heat generation in Friction welding of tube to tube plate using External tool.

3.2 Heat Losses

Total heat generated is transferred to both tool and work piece. Conduction, Convection and radiation in heat transfer are the responsible for heat loss. Heat loss by conduction is takes place through tool.

By Conduction : $Q_{tc} = KA\Delta T/L$

By convection : $Q_c = h(T - T_o)$

By radiation : $Q_r = \epsilon\sigma(T^4 - T^4)$

Total heat loss from surface:

$$Q_{surface} = Q_c + Q_r = h(T - T_o) + \epsilon\sigma(T^4 - T^4)$$

Where: T : Varying temperature

T_o : Room temperature

h : Convection heat transfer coefficient

σ : Boltzmann constant , 5.67 x 10^{-8} $W/_{m^2 °C}$

Heat Loss from bottom

Heat loss from bottom also take place i.e. from tube plate to backing block by means of convection, radiation losses are very less from bottom so considered as negligible .

But it’s difficult to determine convection heat transfer coefficient for bottom part.

$$Q_{bottom} = h_b(T - T_o)$$

3.3 Analytical temperature distribution

Three dimensional temperature distribution is determined by Fourier three dimensional heat transfer equation. The temperature distribution in solids can be determined by solving the heat conduction equation. If the thermo-physical properties are assumed constant and no phase change (i.e. no melting of solids) is considered the heat conduction equation is given by

$$\frac{\partial T}{\partial t} = \alpha \nabla^2 T$$

Where $\alpha = k/\rho C_p$ the thermal diffusivity, k is is the thermal conductivity, ρ is the density and C_p is the specific heat. Solution of Eq. (2.3) with appropriate initial and boundary conditions yields the transient temperature distribution inside the solids.

Continuous Release of Heat

Now, consider a steady (continuous) case of thermal energy generation in an infinite medium. In this case there is no transient term in the governing heat conduction equation and therefore Eq. (2.3) simplifies to

$$\nabla^2 T = 0$$

If the thermal energy generation occurs at a rate $\dot{Q}_T$ at the origin (r = 0) the temperature distribution in the medium is obtained to be

$$T(r,t) = T_i + \frac{\dot{Q}_T}{\rho C_p (4\pi \alpha r)} erfc\left(\frac{r}{2\sqrt{\alpha t}}\right)$$

Where $r = \sqrt{x^2 + y^2 + z^2}$ It should be noted that as $t \to \infty$ the term erfc (0) = 1 and therefore the steady-state temperature distribution in the medium is obtained to be

$$T(r,t) = T_i + \frac{\dot{Q}_T}{\rho C_p (4\pi \alpha r)}$$

Where:

T_i= Initial temperature or ambient temperature (^{o}C)

$\dot{Q}_T$= Heat generation rate (J/sec)

ρ=Material density (kg/m^3)

C_p= Specific heat (kJ/kgK), α=Thermal coefficient of expansion

3.4 Coefficient of friction

It's very difficult to predict value of coefficient of friction in welding process of friction welding of tube to tube plate. Equation for predicting the value of coefficient friction is derived by using Buckingham's Pi theorem and regression curve fitting. Coefficient of friction varying with torque, vertical axial force, radius of tool shoulder and tangential velocity.

Dimensional variables : torque (M), vertical axial force (F_z), radius of tool shoulder (R) and tangential velocity (V), Coefficient of friction (μ)

n = 3 dimensional quantities are considered - mass, length and time.[M L T]

m= 5 dimensional variables (M, F_z, R, V, μ)

m – n = 2 dimensionless groups ($\pi_1\, \pi_2$)

$$\pi_1 = \mu = M^0 L^0 T^0$$

$$\pi_2 = V^a R^b F_z^c M = M^0 L^0 T^0$$

$$V = LT^{-1}, \qquad R = L, \quad F_z = M^1 L^1 T^{-2}, \qquad M = M^1 L^2 T^{-2}$$

So by substituting in π_2

$$[LT^{-1}]^a\ [L]^b\ [M^1 L^1 T^{-2}]\ [M^1 L^2 T^{-2}] = M^0 L^0 T^0$$

So equations

c+1=0, a+b+c+2=0, -a-2c-2=0

Solving these equations

$$a=0, b=-1, c=-1$$

Substituting in π_2

$$\pi_2 = \frac{M}{RF_z}$$

So function will be

$$\pi_1 = f(\pi_2)$$

$$\mu = f(\frac{M}{RF_z})$$

Welding of solid materials is achieved by providing thermal energy in the form of heat for melting or softening the interface between the two materials and bringing or pressing them together. Friction is one of the methods of generating the required thermal energy for welding process. As the solid surfaces rub against each other heat is generated as a result of friction. The heat generated due to friction subsequently diffuses through the bulk of the contacting solid materials. As the heat is necessary for obtaining sound welds, it also affects the mechanical as well as the micro- structural properties of the welded materials in the vicinity of the welding interface. Thermal analysis of friction welding is carried out to determine the resulting temperature distribution around the welding interface and thus allows determination of the high temperature effects on the micro-structure of the materials as well as the quality of the weld.

The analytical solutions developed above provide a general insight of heat generation and temperature distribution in friction welding of tube to tube plate using external tool. Thermal analysis of FWTPET practical welding processes can be approximately simulated by these analytical solutions. In cases where the welding process involves more parameters such as temperature dependent material properties, utilization of assisting gas and complex geometry of materials to be welded, the analytical solutions may not be available. The thermal analysis in such cases must be carried out numerically.