A Numerical Analysis of the Annealing Process in the Irradiated Graphite

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1. Introduction

A numerical analysis for the annealing process in a lump-scaled irradiated graphite bar was conducted to estimate the variations of the local temperature along the axial depth of the graphite, while it is thermally treated in an electric muffle furnace. Two different kinds of thermal approach for the graphite temperature tracking should be taken into account in this system: One is the tracking of the graphite surface temperature variation in accordance with the Wigner energy content in the irradiated graphite[1]. The other is the tracking of the resultant graphite surface temperature according to the furnace temperature condition.

In this paper a numerical analysis was focused on the Wigner energy—residual energy generated in the graphite carbon structure in collision with neutron energy), so that the surface temperature of the irradiated graphite in an annealing process is fully depend on the rate of the Wigner energy extrusion in the given local temperature condition.

2. Mathematical Model and Results

In the mathematical modeling and simulation the followings are the design criteria and the governing equations for an analysis of the annealing process to the irradiated graphite.

2.1 Criteria for System Analysis

With the following basic criteria the irradiated graphite system in a rectangular bar shape are assumed to limit the thermal annealing process model.

1) Anneal the bar size of 10cmx10cmx10cm of graphite bar in the electric muffle furnace. (Muffle furnace size is 30cmx30cmx90cm.)

2) The physical properties of the graphite are summarized in Table I. (Assume that the irradiated graphite is similar to the pure graphite.)

3) A Wigner energy release in the given irradiated graphite is assumed that it follows a typical rate equation as shown in the reference [1]. (noted by the variable activation energy equation(E).)

4) Two thermal approaches in annealing process:

i) Magnitude of Wigner energy = 130 J/g

ii) Furnace temperature starts at 150°C to 250°C in a ramping rate of10°C/min and maintain 60 minutes at 250°C.

iii) Graphite surface temperature starts at 30°C.

2.2 Model Equations

2.2.1 Basic heat conduction problem

The governing equation representing the heat conduction in a rectangular graphite bar is shown as the following form [2]:

$$\rho C_P \frac{\partial T}{\partial \tau} + \kappa \nabla^2 T = Q \qquad (1)$$

$$\nabla^2 = \frac{\partial}{\partial x^2} + \frac{\partial}{\partial y^2} + \frac{\partial}{\partial z^2}$$

Where
ρ = density of graphite
C_P = specific heat capacity of graphite
T = temperature distribution in conduction
τ = time
κ = thermal conductivity of graphite
Q = heat generated or total heat flux.

Table I: Physical Properties of Graphite

	Properties	Remark
Shape (cm×cm×cm)	10× 10× 60	Rectangular bar
Bulk density (g/cm^3)	1.78	At room temp.
Thermal conductivity (W/m·K)	30	At room temp. $\kappa = \alpha \rho C_P$
Heat capacity (kJ/kg·K)	21°C : 0.63 260°C : 1.30 538°C : 1.63	Interpolate with 3 data points

2.2.2 Boundary and initial conditions

The boundary, initial condition and the radiation energy in Eq. (1) are represented by the following, as one-dimensional form of x-direction, Eq. (2):

$$\kappa \frac{\partial T}{\partial x} + hT \Big|_{x=x_0} = 0 \qquad (2)$$

Or, in other notation:

$T = T_0$ at $x = x_0,\ t > 0$

$T = T_i$ for $t = 0,\ x \geq 0$

And relating to the heat transfer equation,

$$Q = A[h(T_f - T_s)^N + V\sigma(\alpha\varepsilon_f T_f^{\ 4} - \varepsilon_s T_s^{\ 4})].$$

For the heat source, Q, is defined by the following simple form like Eq. (3):

$$Q=Q_{fur}+Q_{Wigne} \qquad (3)$$

Q_{fur} = heat source from furnace

Q_{Wigner}= Wigner energy generated inside graphite.

2.2 Simulation Results

With combining of Eq. (1) to (3) the Wigner energy generation in a unit time, a generating rate, during annealing is summarized:

1) No discrepancy between the graphite surface (axial distance = 0.00m) and the graphite center (axial distance = 0.05m).

2) Steady-state temperature of this system is approached at 270~280°C (or 540~550K) in the vicinity of 3000 seconds time spending. (Total Wigner energy was assumed to be130 kJ/kg.)

Fig. 1 shows that the temperature of the graphite lump at any point is approached to the steady state at about 2000 seconds in any case of Wigner energy is dominant or not, since the Wigner energy is not great amount.

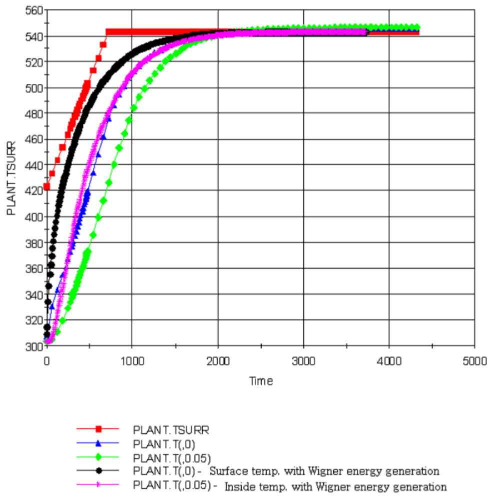

Fig. 1. Temperature changes of graphite lump at each points, respectively, without Wigner energy generation at annealing with linear rise increasing and maintaining isotherm of the surroundings.

In Fig. 1 we can see that the graphite surface temperature is rapidly heated than the inner side, caused by the effect of surroundings. The saturation temperature of the graphite with Wigner energy is approached in higher temperature than that of the graphite without Wigner energy.

3. Conclusions

One-dimensional unsteady-state heat transfer for the annealing process in a rectangular-shaped irradiated graphite lump bar was analyzed using a numerical method. Maximum Wigner energy in the irradiated graphite was assumed 130 kJ/kg. In this calculation, the temperature of the graphite with Wigner energy is approached to a saturation point in somewhat higher temperature range than that of the graphite without Wigner energy. (Here the Wigner energy content is assumed to be rather small.)

REFERENCES

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