Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

Thermal Properties of Beryllium Metal

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1. Introduction

Beryllium is used in thermal reactor as a moderator, reflector or other structure materials due to its excellent neutronic and thermo-physical properties. Beryllium shows a high thermal conductivity values around 200 $Wm^{-1}K^{-1}$ at room temperature. However, these excellent thermal properties are degraded down when it is irradiated with neutrons. For degradation, there are two main causes. The one is defects formed by neutron collisions and the other is helium generated by transmutation. And this helium generation during irradiation is a biggest difference compared to other metallic materials.

It is known that the presence of as-fabricated porosity largely affect thermal conductivity of beryllium. Therefore, in this paper we will suggest a new thermal conductivity equation which consider volume fraction and discuss how this can be applied to irradiation induced degradation of thermal conductivity later.

2. Thermal Properties of Beryllium

7.1. Density of Beryllium

The density is given as a function of temperature by fitting data [1]:

$$\rho_{Be} = 1869.84 - 0.07168T - 1.6151\times10^{-5}T^2 \qquad (1)$$

for the temperature range between 293 to 1287K. But there are considerable differences in values with Ref. [2] while the overall change in density is similar between them. This means that the as-fabricated density should be considered. So we develop a following equation:

$$\rho_{Be} = \rho_0 - 8.14\times10^{-2}(T-300) - 1.62\times10^{-5}(T-300)^2 \quad (2)$$

where ρ_0 is as-fabricated density (kg/m^3). Fig.1 shows that Eq.(2) is consistent with data.

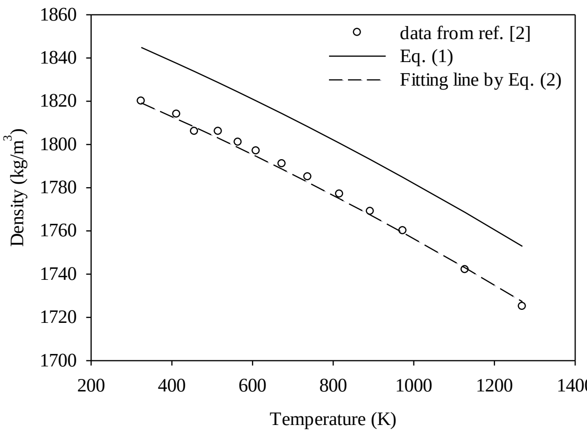

Fig. 1. Density of Beryllium

7.2. Specific Heat of Beryllium

There are some fitting data and equations suggested by other researchers. Although there is no universal equation for it, it is known that specific heat is less affected by impurity and other factors. Thus, we make a new correlation for specific heat of Beryllium including recent data [3, 4] by fitting them. The fitting equation is as follows.

$$C_P = 2.125 + 8.645\times10^{-4}T - 4.32\times10^4T^{-2} \qquad (3)$$

for the temperature range between 300 to 1543 K.
Fig. 2 shows the fitting line with some data. Although there are a few data scattering, the fitting line is seen consistent with them.

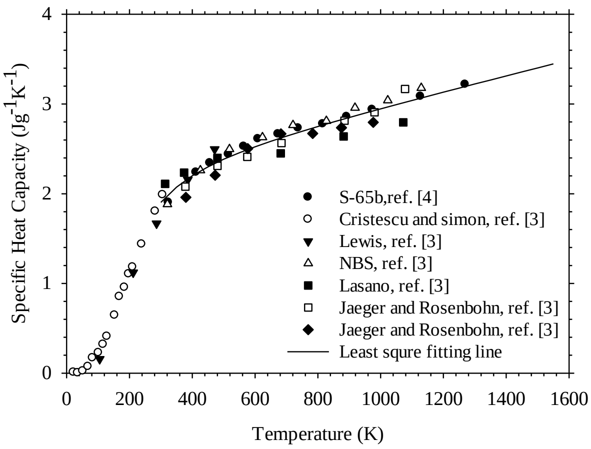

Fig. 2. Specific heat of Beryllium

7.3. Thermal Conductivity of Beryllium

Available data for thermal conductivity of beryllium are limited. Nevertheless, there are thermal conductivity data from other investigators [2-7]. From this, we make a polynomial correlation by the least square fitting. The equation is expressed as:

$$k = 254.2 - 0.2637T + 9.892\times10^{-5}T^2 \qquad (4)$$

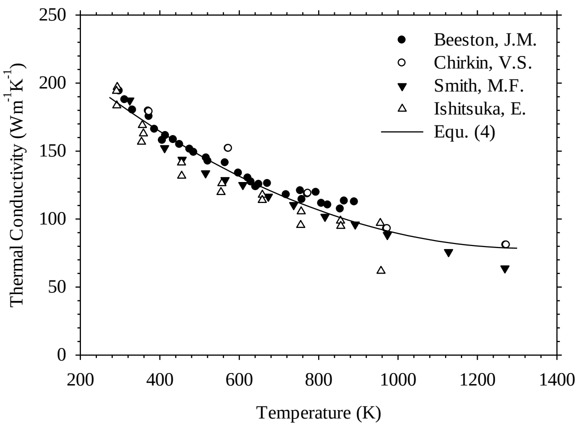

Fig. 3. Thermal conductivity of Beryllium

However thermal conductivity is affected by impurity, grain size, and porosity. According to Wockham A.J. data[6], thermal conductivity is affected by various manufacturing and processing methods. Therefore, we need to develop a new correlation which considers these factors. We assumed as-fabricated porosity is the main factor affecting thermal conductivity based on some experiment data [5, 6]. So other factors like defects, impurity, and grain size are assumed negligible. However there is no universal law for the degradation in conductivity by porosity volume fraction because size, shape and distribution of pores have wide variations. In this work, we do not consider the effects of shapes and distributions of pores and consider only the volume fraction of pores. So we assume the pores whose shape is sphere are distributed uniformly. Although there have been many quantitative methods to deal with the effects of porosity on the bulk thermal conductivity, for the present work, the Maxwell-Eucken equation is suggested [8]:

$$k = \frac{1-P}{1+\beta P} k_{TD} \quad (5)$$

where k_{TD} is the thermal conductivity of the matrix with 100% theoretical density, and P porosity in fraction. . Here β is used to correct the characteristics of pores; the more closed pores, the higher the value. For a high closed pore case, β can be 2 or even 3. In this work, β=2 is adopted. Because there are no data for thermal conductivity of the 100% theoretical density, the estimation is done based on the M.F. Smith data [2] :

$$k_{TD} = 6008 \cdot T^{-0.5946} \quad (6)$$

Porosity can be calculated by Eq. (2) if as-fabricated density is given:

$$P = \left(1 - \frac{\rho_{Be}}{\rho_{the}}\right) \quad (7)$$

where ρ_{Be} is obtained from Eq. (2) and ρ_{the} is theoretical density (1850kg/cm^3). Fig. 5 shows the thermal conductivity difference when as-fabricated densities are 100, 90, 80, and 70%. As the volume fraction increases, the thermal conductivity decreases. This is consistent with data [5].

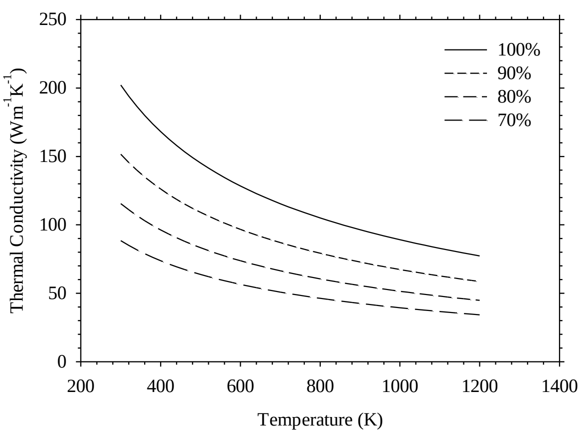

Fig. 4 Volume fraction effect on thermal conductivity

4. Conclusions

This study was performed to develop a new correlation of thermal conductivity of Beryllium. Although there are many factors like BeO contents, impurity level, grain size, and porosity, we assumed porosity will be the dominant factor for thermal conductivity. Therefore, a new correlation which consider volume fraction by applying Maxwell-Eucken equation is developed and this is consistent to some degrees. However, increasing impurity level and decreasing grain size will decrease thermal conductivity. Therefore, we need to consider their effects although we assume BeO contents, impurity, and grain size do not make noticeable effects in the future.

Furthermore, thermal conductivity degradation by neutron irradiation should be considered afterward. There are two main factors for the thermal conductivity degradation: the one is defects formed by neutron collisions and the other is helium generated by transmutation of Be. It is known that they make a considerable degradation of conductivity. Beryllium is known there are considerable volume increases by helium accumulation. Therefore, we anticipate our suggested model can be applicable if it has been developed furthermore considering irradiation induced swelling.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Education, Science and Technology) (No. 2011-0031771)

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