Ibn Al-Haitham Journal for Pure and Applied Science | مجلة إبن الهيثم للعلوم الصرفة و التطبيقية
No. 1 Vol. 25 Year 2012 | 2012 السنة 25 المجلد 1 العدد

Using Gamma Ray Transmission for Determination of Porosity in Doped Alumina Samples

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Received in: 27April 2011,Accepted in: 18October2011

Abstract

In this study, gamma ray transmission method have been used to determine the total porosity in four samples: pure Alumina (Al_2O_3), Al_2O_3 + (0.2wt%)MgO , Al_2O_3 + (0.6wt%)Y_2O_3 and Al_2O_3+ (8wt%) ZrO_2 .

The experimental setup for the gamma ray transmission consist of ^{137}Cs gamma source (662 KeV), a NaI (Tl) scintillation detector measured the attenuation of strongly collimated gamma beam through alumina samples.

The porosity obtained by the gamma ray transmission method were compared with themeasurements by conventional (Archimedes) method. It was observed that the porosity measurement by gamma ray transmission method has the advantage of being accurate, nondestructive and fast analysis.

Keywords: Gamma ray, Attenuation coefficients, Porosity, Doped alumina

Introduction

Porosity is an important parameter commonly used to describe the behavior of prose material, that is of great interest in many areas such as medicine, petroleum, engineering, metallurgy , nuclear reactor technology and other applications [1, 2].

The porosity of a medium can be expressed as a ratio of volume of the void space to the bulk volume, that is a dimensionless quantity usually expressed in percentage.

Measurement of material's porosity are usually performed by conventional methods like Archimedes porosimetry and mercury injection porosimetry [3, 4]. However the gamma ray transmission technique is allows determination of the porosity without interfering in the physical integrity of the sample [5]. The method of gamma ray transmission was applied in the measurement of reservoir rocks porosity by Phogat and Aylmore [6]. Oliveira et al. uses x ray in porosity measurements of titanium sintered foams [7]. Demir et al. uses gamma ray transmission in porosity measurements of soil[8].

Alumina exhibit low volume dilatation and high thermal conductivity coefficient, another application of this material is to cover recipients exposed to thermal shocks and high temperatures (up to 1700 °C)

It is very important to determine the porosity of sintered materials because this parameter has a large influence the efficiency of there applications. In the present work, gamma ray attenuation coefficient and porosity of pure Alumina (Al_2O_3), Al_2O_3 + (0.2wt%)MgO, Al_2O_3 + (0.6wt%) Y_2O_3 and Al_2O_3+ (8wt%)ZrO_2 are determined by using gamma ray transmission method. The gamma ray attenuation measurements have carried out , using ^{137}Cs radioactive source.

Experimentation

1. Samples preparation

High purity α-Alumina was used as the starting powder. The powder characteristic was 0.3μm average particle size.

Samples of alumina containing weight percentages of MgO (0.2wt%), Y_2O_3 (0.6wt%) and ZrO_2 (8wt%.) were prepared by mixing for (20 hrs). After that, the mixture was pressed to pellets with 20mm diameter and approximately 2mm thickness. These pellets were heated at 1550°C in air for 14hrs.

Sintered densities were measured by using the Archimedes method with mercury as the immersion medium.

2. Experimental setup

The gamma ray transmission system consisted of radioactive source ^{137}Cs (662 KeV) with an activity 100 μci . The radioactive source was shielded by the pin-hole lead collimator to obtain a narrow beam (3mm diameter). The intensities of gamma photons were measured by using NaI(Tl) scintillation detector (Saint- Gobain Crystals Bicron model 1.5in.× 2 in. made in U.S.A.). The detector was coupled to pre-amplifier, amplifier, power supply and computer analyzer with LD Didactic GmbH sensor-cassy for data acquisition and analysis the obtain areas. The detector was also housed in a thick lead jacket with a 10 mm diameter holed collimator.

Fig.1 shows schematic arrangement of the experimental setup used in the present study.

Samples were used in the form of a tablets plates with approximately 20mm diameter and 2mm thickness.

Each spectrum was recorded for a period of 1000 sec, to reduce the statistical error. Background spectra were recorded for the same time period and subtracted from each spectrum.

3. Porosity determination

For determination of the total porosity by gamma ray transmission method, it is necessary to determine the linear attenuation coefficient for the materials. The attenuation of a narrow collimated beam of gamma rays for a given energy can be obtained by the relationship [8,9]:

$$I = I_0 e^{-\mu x} \quad .... \quad (1)$$

Where I_0 is the initial intensity of gamma rays , I is the intensity of gamma rays after attenuation through a media of thickness x and μ is the linear attenuation coefficient of the material.

Equation (1) may also be written as:

$$\mu = \frac{1}{x} \ln \frac{I_0}{I} \quad .... \quad (2)$$

Total porosity (Pt) of a medium can be described as[10,11]:

$$Pt = \frac{\mu_p - \mu_a}{\mu_p} \quad .... \quad (3)$$

Where μ_p (cm^{-1}) is the linear attenuation coefficient of the sample at the particle density and μ_a (cm^{-1}) is the linear attenuation coefficient of the sample crossed gamma ray beam.
The linear attenuation coefficient of the sample (μ_a) was experimentally determined by measuring the gamma attenuation through a known thickness of sample for 662 KeV photons.
The linear attenuation coefficient of the sample at the particle density (μ_p) was accomplished by the application of the software XCOM [12], taking into account the chemical composition and bulk density of the sample.
For determination of the total porosity by conventional method (Archimedes), using the following relation [10, 11]:

$$Pt = \frac{w_s - w_d}{w_s - w_{ss}} \quad .... \quad (4)$$

Where W_s is the weight in the air of the sample saturated with water, W_d is the dry sample weight in the air and W_{ss} is the weight saturated of water suspended in water.

Results and Discussion

Measurement of material bulk density involves the determination of the mass and the volume of a given amount of alumina samples. Table 1 shows the measured bulk density, average values obtained for linear attenuation coefficients of the samples(μ_a) and linear attenuation coefficients of the samples at particle density (μ_p).
Table 2 shows the average total porosity for the alumina samples by gamma-ray transmission method (calculated by eq.3) and by Archimedes method (calculated by eq.4).
The values obtained by gamma ray method are larger than that obtained by Archimedes method, because the gamma ray transmission method characterizes total porosity while the Archimedes method characterizes only connected pores that represents apportion of the total porosity.

Conclusions

The total porosity(%) of alumina samples were determined by gamma ray transmission method and Archimedes method. The results obtained for the total porosity(%) by gamma ray method shown deceasing behavior with increasing the linear attenuation coefficient of the sample (μ_a) crossed gamma ray beam.
The gamma ray transmission method gives characterizes total porosity while the Archimedes method characterizes only effective porosity or connected pores that represents apportion of the total porosity.
The comparison between experimental results gives the gamma ray transmission method appears to offer advantages such as inexpensive, non destructive and fast analysis according to conventional Archimedes method.

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Table (1): Experimental values of bulk density , linear attenuation coefficients of the samples at particle density (μ_p) and linear attenuation coefficients of the samples crossed gamma ray beam. (μ_a)

Material	Bulk Density ($g.cm^{-3}$)	μ_p (cm^{-1})	μ_a (cm^{-1})
Al_2O_3	2.40±0.013	0.18211	0.1349±0.0004
Al_2O_3 + 0.2wt%MgO	2.65±0.015	0.20108	0.1537±0.0009
Al_2O_3 + 0.6wt% Y_2O_3	2.75±0.016	0.20864	0.1714±0.0010
Al_2O_3+ 8wt%ZrO_2	2.89±0.015	0.21891	0.1855±0.0005

Table (2): Average values of total porosity for the alumina samples obtained by gamma-ray transmission method and by conventional method (Archimedes)

Material	Total porosity (%)	
	gamma transmission	Archimedes
Al_2O_3	25.9198±0.2196	22.10±1.00
Al_2O_3 + 0.2wt%MgO	23.5323±0.4477	20.67±1.30
Al_2O_3 + 0.6wt% Y_2O_3	17.8733±0.5195	16.64±1.50
Al_2O_3+ 8wt% ZrO_2	15.2619±0.2283	13.78±1.12

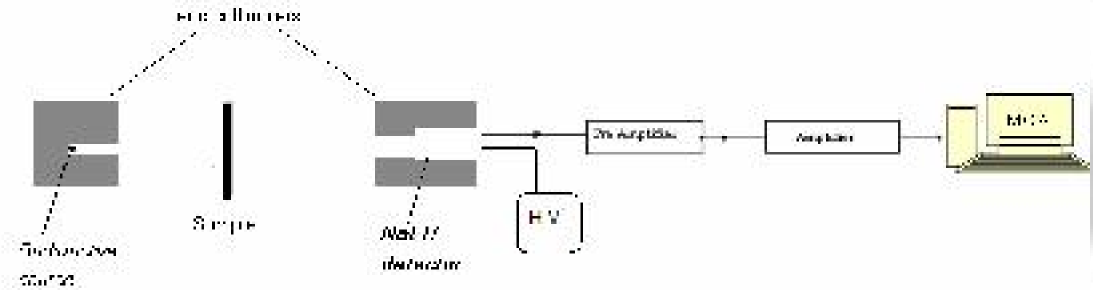

Fig.(1): Experimental setup for the measuring of linear attenuation coefficients

استخدام نفاذية أشعة كاما لتعيين المسامية في عينات الألومينا المشوبة

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استلم البحث في : 27 نيسان 2011، قبل البحث في : 18 تشرين الاول 2011

الخلاصة

تم في هذه الدراسة استخدام تقنية نفاذية أشعة كاما لتعيين المساميةِ الكليّةِ لأربع عيناتِ : الألومينا النقية (Al_2O_3) ، Al_2O_3 +(0.6wt%) Y_2O_3 ، Al_2O_3 +(0.2wt%)MgO و Al_2O_3+ (8wt%)ZrO_2 .

تضمنت منظومة القياس كل من مصدر أشعة كاما السيزيوم – 137 الباعث لأشعة كاما (فوتون) ذو الطاقة 662 كيلو إلكترون فولت والكاشف الوميضي يود يد الصوديوم المنشط بالثاليوم NaI(Tl) لقياس توهين حزمة أشعة كاما في عينات الألومينا.

قورنت المساميةُ التي تم الحصول عليها بطريقةِ نفاذية أشعة كاما مع الطريقة التقليدية (طريقة أرخميدس). لوحظَ ان طريقة نفاذية أشعة كاما تمتلك فوائد عديدة منها: إعطاء نتائج دقيقة وغيرِ اتلافية للنماذج وسريعة.

الكلمات المفتاحية: أشعة كاما ،معاملات التوهين، المسامية،الألومينا المشوبة