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# Thermal Diffusivity Measurement of Abrasive Paper Using Photoacoustic Technique

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## ABSTRAK

Pengukuran nilai resapan terma untuk dua jenis kertas pasir dilaporkan. Untuk tujuan ini dua jenis kertas pasir, silikon karbaid dan aluminium oksida dipilih sebagai sampel kajian. Nilai resapan terma kertas pasir silikon karbaid dengan saiz grit 320, 360, 400, 600, 800, 1000, 1200 dan 1500 telah diukur. Sebaliknya, untuk sampel kertas pasir aluminium oksida hanya dua sampel (saiz grit 120 dan 240) sahaja dipilih dalam kajian ini. Semua pengukuran dilakukan pada suhu bilik dengan permukaan berpasir menghadap kepada sinar laser. Nilai resapan terma efektif yang diperoleh untuk silikon karbaid adalah dalam julat (5.1 - 8.9) x $10^{-2}$ $cm^2/s$ iaitu lebih kecil berbanding nilai resapan terma untuk seramik silikon karbaid yang disediakan daripada serbuk silikon karbaid. Sebaliknya untuk kertas pasir aluminium oksida, nilai resapan terma efektif (0.18 $cm^2/s$ dan 0.35 $cm^2/s$) adalah lebih tinggi daripada nilai resapan terma seramik aluminium oksida yang pernah dilaporkan. Struktur permukaan sampel dikaji dengan menggunakan SEM pada pembesaran 100X.

## ABSTRACT

Measurements of thermal diffusivity of two types of abrasive papers are reported. We have chosen silicon carbide and aluminium oxide abrasive papers as our samples. Thermal diffusivity of silicon carbide abrasive paper with the grit size of 320, 360, 400, 600, 800, 1000, 1200, and 1500 were measured. On the other hand, only two grit size (120 and 240) of aluminium oxide abrasive papers were chosen in the present experiments. All the measurements were carried out at room temperature with the abrasive surface facing the laser beam. The effective thermal diffusivity values obtained for silicon carbide are in the range of (5.1 - 8.9) x $10^{-2}$ $cm^2/s$, which is lower than the value of thermal diffusivity of pellet ceramic silicon carbide prepared from silicon carbide powder. For aluminium oxide abrasive papers the effective value of thermal diffusivity (0.18 $cm^2/s$ dan 0.35 $cm^2/s$) is higher than the value reported for aluminium oxide ceramic. The surface structure of the sample was investigated using SEM with the magnification of 100X.

**Keywords: Abrasive paper, thermal diffusivity, photoacoustic technique, silicon carbide, aluminium oxide**

## INTRODUCTION

Abrasive paper is a tough paper coated with an abrasive material such as a silica, garnet, silicon carbide, or aluminium oxide. It is mainly used for grinding, polishing metals, machine tools, car bodywork and furniture. Before the 1950s, silicon carbide was available only through the industrial Acheron process for making abrasive material. Silicon carbide is a high performance material selectively used throughout diverse industries for severe applications, including condition of high abrasive wear, high corrosion, high power and high temperature electronic. In this paper, we report the photoacoustic measurement of the effective thermal diffusivity of abrasive papers (i.e. silicon carbide and aluminium oxide abrasive papers). Generally a grit number is used to specify the particle size of abrasive material, i.e. the higher grit number, the smaller the particle size.

The thermal diffusivity, $\alpha$ is of direct importance in the heat-flow studies, as it determines the rate of periodic or transient heat propagation through a medium. Abrasive papers are used occasionally for polishing purposes. Therefore, its thermal diffusivity is important so as to maintain the physical surface of samples. Bigger particle size (higher thermal diffusivity) will destroy the physical surface of the samples.

The thermal diffusivity value of ceramic aluminium oxide has been determined by using flash method (Yano *et al.* 2000) and photothermal deflection technique (Chung *et al.* 1997). During the past two decades, the use of photoacoustic (PA) measurements has gradually diffused into a wide range of branches of science, from agricultural and medical sciences to environmental sciences in general (Lima *et al.* 2000). This encouraging process can be connected to the sensitivity of the PA signal to changes in the sample's physical characteristics due to modifications in processing conditions.

## EXPERIMENT SETUP

The open photoacoustic cell (OPC) for measuring thermal diffusivity has been proposed by Perondi *et al.* (1987). The OPC technique is simple and the easiest method for measuring thermal diffusivity, $\alpha$ of solid sample such as metals, ceramics, polymers and composites. The OPC experiment set-up used for the PA measurement of thermal diffusivity at room temperature is shown in *Fig.1.* The mechanically modulated beam from He-Ne laser (Model Melles Griot, 05-LHR-828) with output power 30 mW is focused onto the sample. When the modulated laser beam was illuminated onto the front surface of the sample, the heat generated in the sample diffuses to the air in the small photoacoustic chamber. Hence, the pressure in the air chamber oscillates at the chopping frequency, which can be detected by the sensitive microphone (electret microphone-Cirkit U.K.). This microphone has a 2.5 mm diameter of circular opening hole, a metallized electret diaphragm, 45 μm long air gap separating the diaphragm and a metal back-plate. This typical microphone design is schematically shown in *Fig. 2.* The resulting signals depend not only on the

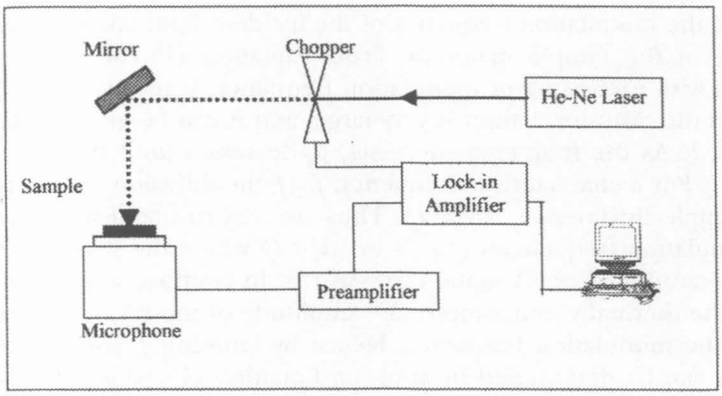

*Fig. 1: Experiment setup of the open photoacoustic cell technique*

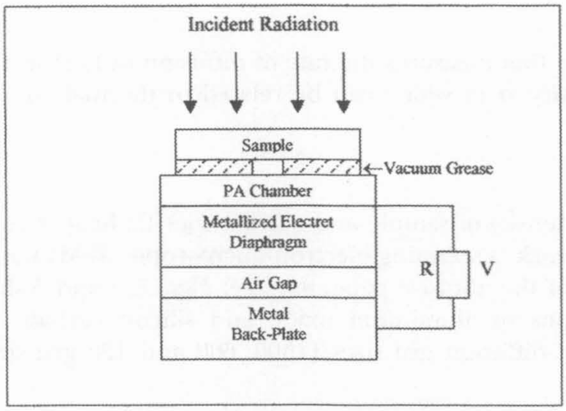

*Fig. 2: Schematic view of the eletret microphone used as the open photoacoustic cell detection in the thermal diffusivity measurements*

amount of heat generated in sample (i.e. on the optical-absorption coefficient and the light-into-heat conversion efficiency of the sample) but also on how heat diffuses through the sample. The photoacoustic signal being generated was amplified by a preamplifier (SR 560) and then processed by a lock in amplifier (SR 530). The amplitude and phase of the PA signals were recorded and analyzed for thermal diffusivity value.

The theory of the PA effect in solid sample has been described by R-G theory in 1976 (Rosencwaig and Grasho 1976). According to this theory, the heat generated in the sample is transferred to the gas immediately upon contact. An important parameter involved is the thermal diffusion length of the sample, $\mu_s$ which can be defined in terms of thermal diffusivity, $\alpha$ by simple relation as

$$\mu_s = \sqrt{\alpha / \pi f} \quad (1)$$

where $f$ is the modulation frequency of the incident light and $\alpha$ is the thermal diffusivity of the sample materials. From Equation (1), we can see that $\mu s$ decreases with increasing of modulation frequency. It means that, at very low frequency the diffusion length is very large, and it can be greater than sample thickness, $l_s$. As the frequency increases, $\mu_s$ decreases until it becomes of the order of $l_s$. For a characteristic frequency, $f = f_c$ the diffusion length, $\mu_s$ is equal to the sample thickness, $l_s$ ($\mu_s = l_s$). Thus, we may distinguish two regimes; at high modulation frequencies ($f > f_c$) or ($\mu_s < l_s$) where the sample is thermally thick, the amplitude of PA signal varies as $f^{-1.5}$. In contrast, when ($f < f_c$) or ($\mu_s > l_s$) for the thermally thin sample, the amplitude of the PA signal decreases as $f^{-1}$ with the modulation frequency. Hence by knowing $f_c$ and $l_s$, the thermal diffusivity can be determined by applying Equation (1), which corresponds to the situation ($l_s = \mu_s$), i.e.

$$\alpha_s = \pi f_c l_s^2 \tag{2}$$

The quantity that measures the rate of diffusion of heat in the sample is the thermal diffusivity, $\alpha$ in which can be related to thermal conductivity, k as

$$\alpha = k/\rho c \tag{3}$$

where $\rho$ is the density of sample and c is the specific heat at constant pressure. In the present work, a scanning electron microscope (SEM) was used to analyze the roughness of the abrasive paper surface. *Figs. 3, 4* and *5* show examples of SEM micrographs of aluminium oxide and silicon carbide abrasive papers surface taken at different grit sizes (1500, 600 and 120 grit size).

## RESULTS AND DISCUSSION

Photoacoustic signals of aluminium oxide and silicon carbide abrasive papers with grit size of 120 and 1500 are respectively shown in *Fig. 6*. In order to determine the characteristic frequency, where the sample changes its behavior from thermally thick to thermally thin, a method proposed by Da Costa and Siquire (1996) was employed. Therefore the graph of ln (PA signal) versus ln (chopping frequency) has been plotted. Typical examples of ln (PA) signal as a function of ln ($f$) of aluminium oxide ($5.08 \times 10^{-2}$ cm thickness) and silicon oxide ($1.83 \times 10^{-2}$ cm thickness) abrasive papers are respectively shown in *Fig. 7*. The two regimes can be distinguished by two different inclinations of straight lines. The characteristic frequency, $f_c$ is the frequency at which the sample changes its behavior from thermally thick to thermally thin. In these two cases, the $f_c$ was determined to be 40.64 Hz and 52.48 Hz that correspond to the thermal diffusivity values of 0.350 $cm^2s^{-1}$ and 0.0551 $cm^2s^{-1}$ respectively. The same procedure was conducted for the other abrasive paper samples. All the thermal diffusivity values of abrasive paper samples obtained in this work are listed in Table 1.

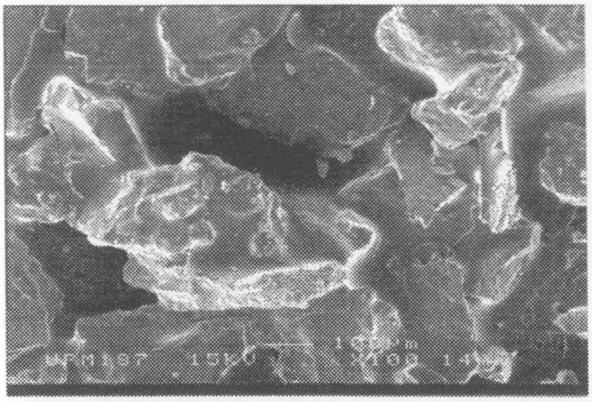

*Fig. 3: SEM micrograph of aluminium oxide abrasive paper with grit size 120*

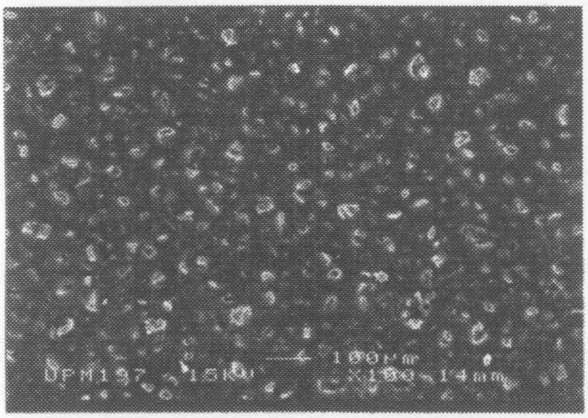

*Fig. 4: SEM micrograph of silicon carbide abrasive paper with grit size 120*

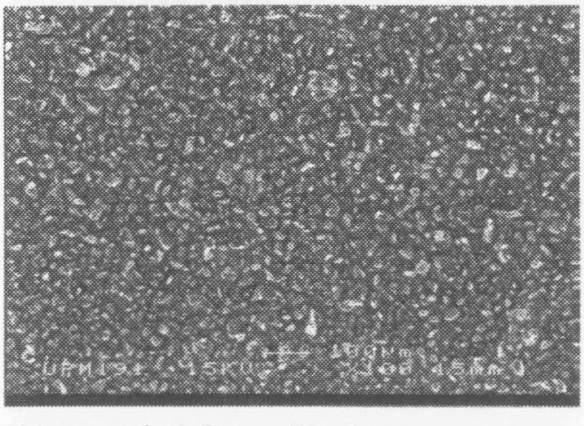

*Fig. 5: SEM micrograph of silicon carbide abrasive paper with grit size 1500*

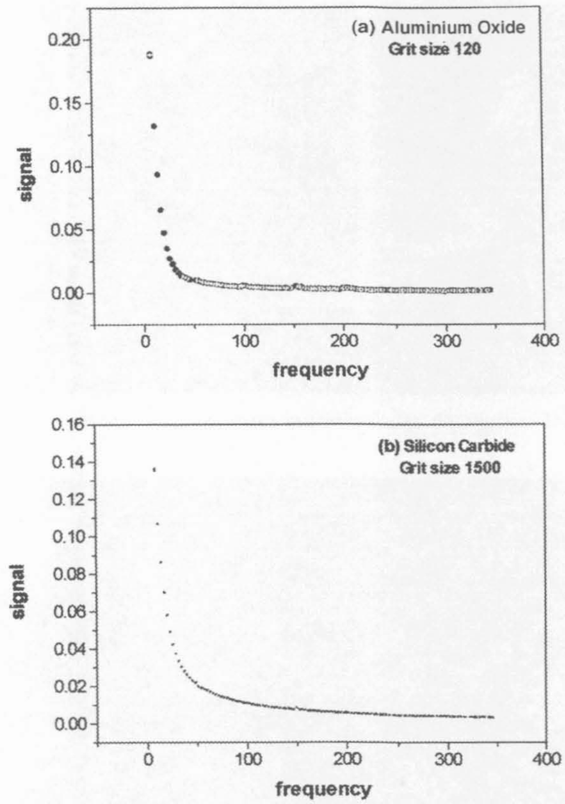

*Fig. 6: Plot PA signal amplitude as a function of the modulation frequency for (a) Aluminium oxide abrasive paper (b) Silicon carbide abrasive paper*

TABLE 1
Thermal diffusivity of aluminium oxide and silicon carbide abrasive papers measured by photoacoustic technique

| Grit Size | Thermal diffusivity, α ($cm^2s^{-1}$) | |
|---|---|---|
| | Aluminium Oxide (Abrasive paper) $AlO_3$ | Silicon Carbide (Abrasive paper) SiC |
| 120 | 0.3500 | - |
| 240 | 0.1800 | - |
| 320 | - | 0.0798 |
| 360 | - | 0.0886 |
| 400 | - | 0.0727 |
| 600 | - | 0.0552 |
| 800 | - | 0.0511 |
| 1000 | - | 0.0651 |
| 1200 | - | 0.0620 |
| 1500 | - | 0.0551 |

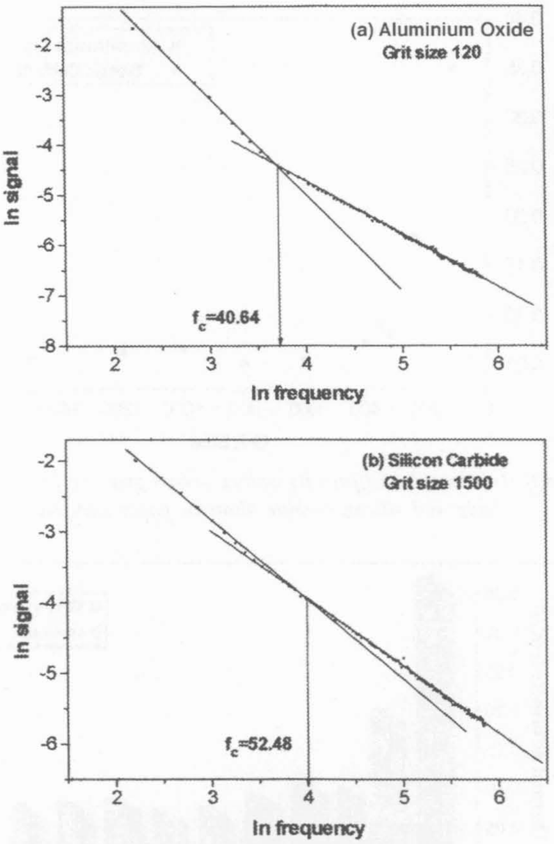

*Fig. 7: Plot of 1n (PA signal) versus 1n (chopping frequency) for*
*(a) Aluminium oxide abrasive paper with grit size of 120*
*(b) Silicon carbide abrasive paper with grit size of 1500*

The results for all abrasive paper samples measured in this study are summarized in *Fig. 8* and *Fig. 9.* The highest effective thermal diffusivity ($\alpha$ = 0.350 $cm^2s^{-1}$) was obtained from aluminium oxide abrasive paper which corresponds to the grit size of 120. The lowest effective thermal diffusivity ($\alpha$ = 0.0511 $cm^2s^{-1}$) was obtained from silicon carbide abrasive paper that corresponds to the grit size of 800. In general, the effective thermal diffusivity values of silicon carbide abrasive paper are lower than the aluminium oxide abrasive paper.

We observed that the thermal diffusivity values of aluminium oxide abrasive paper (grit size 120 and 240) obtained in the present measurements are higher than the values reported by Hazelton *et al.* 1998 (i.e. (0.100 $cm^2s^{-1}$). On the other hand, for silicon carbide abrasive paper, our thermal diffusivity values are lower than the values of thermal diffusivity of silicon carbide ceramic (0.21 - 0.69 $cm^2s^{-1}$) as reported by Sánchez-Lavega *et al.* 1997. The differences among

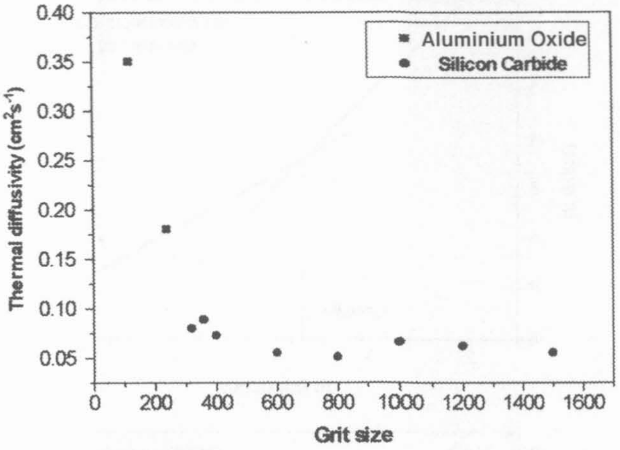

*Fig. 8: Effective thermal diffusivity values versus grit size for aluminium oxide and silicon carbide abrasive paper samples*

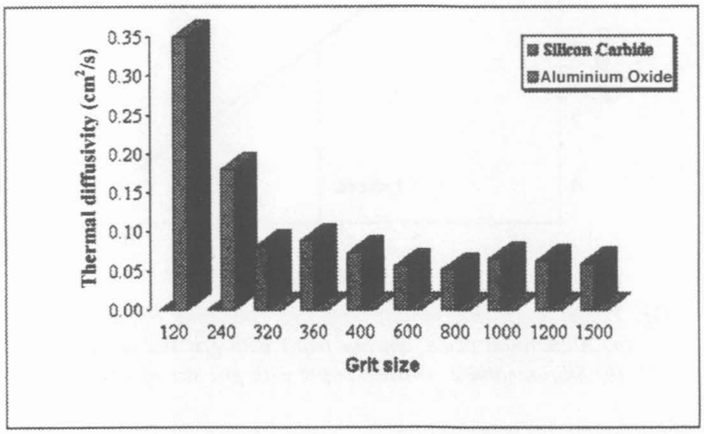

*Fig. 9: Histrogram shows the relative effective thermal diffusivity of aluminium oxide and silicon carbide abrasive papers as presented in Fig. 8*

the results for thermal diffusivity obtained in the present measurements are due to the different sizes of the abrasive materials used in processing. In addition to that, it may also be affected by the different processing condition and surface porosity of the abrasive papers, and the paper material of the abrasive paper itself.

## CONCLUSION

The effective thermal diffusivity of silicon carbide and aluminium oxide abrasive papers has been determined using the open photoacoustic cell detection. The values of effective thermal diffusivity measured at room temperature of 10 different sizes of abrasive paper samples are varied from 0.050 to 0.350 $cm^2s^{-1}$. Since the physical and processing conditions are different, the results obtained in the present work are found to be different with the values of thermal diffusivity of aluminium oxide and silicon carbide ceramics.

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