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Thermal diffusivity of Al-Mg based metallic matrix composite reinforced with Al$_2$O$_3$ ceramic particles

A. Cruz-Orea$^1$, J. E. Morales$^2$, R. Saavedra S$^2$ and C. Carrasco$^3$

$^1$Departamento de Física, Centro de Investigación y de Estudios Avanzados del IPN. A.P. 14.740, C.P. 07360, México DF, México.
$^2$Departamento de Física, Facultad de Ciencias Físicas y Matemáticas, Universidad de Concepción, Casilla 160-C, Concepción – Chile.
$^3$Departamento de Ingeniería de Materiales, Facultad de Ingeniería, Universidad de Concepción, Casilla 160 – C, Concepción - Chile.

*Corresponding author’s e-mail address: orea@fis.cinvestav.mx

Abstract. Thermal diffusivities of Al-Mg based metallic matrix composite reinforced with ceramic particles of Al$_2$O$_3$ are reported in this article. The samples were produced by rheocasting and the studied operational condition in this case is the shear rate: 800, 1400 and 2000 rpm. Additionally, the AlMg base alloy was tested. Measurements of thermal diffusivity were performed at room temperature by using photoacoustic technique.

1. Introduction

The metal matrix composite materials (MMCM) are solid compounds formed by a metallic matrix where a second constituent is introduced but they are not chemically mixed[1-2]. The MMCM are an important type of materials due to the wide range of applications in several industries; the best example is the fabrication of aerospace and automotive component. Depth knowledge of their preparation and physical properties are absolutely necessary to exploit their potential applications. The aluminium based MMCM has been widely studied because of their greater possibilities to answer the required structural and thermal properties [3]. In particular we are studying the aluminium-magnesium based alloys, specifically matrix alloy A520 (10% of Mg) reinforced with ceramic particles of Al$_2$O$_3$. This material has attractive physical properties such as hardness, low density and high mechanical resistance [4].

To investigate the thermal properties of the MMCM we use the photoacoustic (PA) experimental technique. In this article we report the influence of the shear rate, during rheocasting process, on the thermal diffusivity of these Al-MMCM materials. Thermal diffusivities were determined by using PA technique in a heat transmission configuration [5]. Experiments were based on the standard model proposed by Rosencwaig-Gersho[6], model that has been proved to be a good scientific approximation to get reliable thermal properties of materials[7, 8].
2. Experimental

2.1 Sample preparation

Al-Mg based metal matrix composite reinforced with ceramics particles of $\text{Al}_2\text{O}_3$ were produced by using rehocasting technique[9, 10]. All the samples have in common the element components, amount of ceramic particles introduced, temperature treatment and agitation time. The only variable parameter was the shear rate, the actual values were 800, 1400 and 2000 rpm for Alloy samples $a$, $b$ and $c$ respectively. All samples show an aluminium metallic colour. Final studied samples had disk shape with parallel base faces. Thickness of samples was achieved by mechanical polishing. Table 1 shows final thickness used for the different samples.

2.2 Photoacoustic set up

The thermal diffusivity of the samples was obtained by using the PA technique in a heat transmission configuration [5]. The PA experimental set up consists of a 250 W halogen-tungsten lamp whose light beam is modulated by a mechanical chopper (SRS model 540) and focused onto the sample by means of an optical fiber. The home made photoacoustic (PA) cell has a cylindrical cavity with a 6 mm opening where the sample is attached with vacuum grease; the PA cell is connected to a B&K microphone, model 4943, through a 1 mm diameter- 10 mm long hole. The signal coming from the microphone is connected to a lock-in amplifier (SRS model 530), which gives us the PA signal amplitude and phase. The data is recorded as a function of light modulation frequency ($f$) by using a PC which also assists the running experiment.

3. Theory

By applying the Rosencwaig-Gersho[6] theory for a thermally thick regime (i.e. $l > \mu$, where $l$ is the thickness of sample and $\mu = (\alpha / (\pi f)^{1/2})$, under heat transmission configuration it can be found that both, PA signal amplitude and phase, are $\sqrt{f}$ dependent. In the case of thin metal sheets this regime is usually gotten at very high frequencies, where the signal to noise ratio is too small, and therefore is difficult to have a reliable PA signal in order to obtain the sample thermal diffusivity. Nevertheless by applying the same theoretical model developed by Rosencwaig and Gersho in the approximation proposed by Calderon et al.[8], for thin materials ($l < \mu$) under a diffusion regime, the PA signal phase as a function of the light modulation frequency is given by:

$$\phi = -\frac{1}{\alpha f_c^2} f + \frac{3}{4} \pi$$

where $f_c = \alpha / (\pi l)^2$ and $f < (\pi / 2)^2$. $f_c$ represents the frequency where $l = \mu$. The advantage of this approximation is that the range of modulation frequencies, where the measurements are performed, is below those normally used for thermally thick regime, hence, the signal to noise ratio will be more reliable. Then, by fitting eq. (1) to experimental PA signal phase the sample thermal diffusivity can be obtained.

4. Results and discussion

Figure 1 shows the PA signal phase versus the modulation frequency for Allow $a$ sample. Also in the other samples the phase shows linear frequency dependence, as expected in the frequency range where the Eq. (1) is valid. The thermal diffusivity of samples was obtained by fitting the experimental data in order to obtain the slope $1/(\pi f_c)$. The obtained $\alpha$ values for the studied samples are close to the reported $\alpha$ value for aluminium alloy 5056 (5.2% Mg, 0.1% Cr) which is 0.6 cm$^2$/s [11]. Evidently the shear rate of steering is a determinant parameter, as can be seen from Table 1. The mentioned dependence of diffusivity respect to the shear rate comes from the fact that by increasing shear rate the globular structure becomes rounder and smaller and the Mg concentration increases in smaller regions of the alloy[4].
Figure 1 PA signal phase as function of the light modulation frequency for Alloy a sample. The solid line is the best fitting of equation 1 to the experimental data (square dots).

Table 1. Thermal diffusivity of Al-MMCM composite

| Sample   | Speed(rpm) | \( l \) (\( \mu m \)) ± 5 \( \mu m \) | \( m(s^{-1})(x10^{-3}) \) | \( \alpha (cm^2/s) \) |
|----------|------------|--------------------------------------|-----------------------------|------------------------|
| AlMg     | 6          | 345                                  | 2.72 ± 0.07                 | 0.47 ± 0.07            |
| Alloy a  | 3          | 585                                  | 5.38 ± 0.12                 | 0.64 ± 0.02            |
| Alloy b  | 3          | 382                                  | 2.59 ± 0.17                 | 0.56 ± 0.04            |
| Alloy c  | 2          | 383                                  | 3.01 ± 0.14                 | 0.49 ± 0.02            |

5. Conclusions

In this work the thermal diffusivity for Al-Mg based MMCM is reported. The thermal diffusivity values were obtained by using the PA technique in a heat transmission configuration. We used the approximation proposed in reference [8] where the range of modulation frequencies, for the PA measurements, is below those normally used for the thermally thick regime, hence the signal to noise ratio will be higher. The obtained thermal diffusivities are higher than the Al-Mg matrix alloy due to both to the presence of \( Al_2O_3 \) ceramic reinforcement as well as to the effect of shear rate.

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