Electrical Conductivity of SiC/Si Composites Obtained from Wood Preforms

Marco Antonio Béjar, Rodrigo Mena, and Juan Esteban Toro

Department of Mechanical Engineering, University of Chile, Casilla 2777, Santiago 6511265, Chile

Reprint requests to M. A.; Tel.: +56 2 9784594; fax: +56 2 6896057. E-mail: abejar@ing.uchile.cl

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Biomorphic SiC/Si composites were produced from pine and beech wood, and the corresponding electrical conductivity was determined as a function of the temperature. Firstly, wood preforms were pyrolized at 1050 °C in nitrogen. Then, the pyrolized preforms were impregnated with liquid silicon and kept at 1600 °C for 2 h in vacuum. The SiC/Si composites were obtained due to the produced carbothermal reaction. As expected, the resulting electrical conductivity of these composites increased with the temperature and with the silicon content.

Key words: Biomorphic; Bioceramics; SiC.

1. Introduction

Silicon carbide (SiC) is a semiconductor ceramic which can be used as a structural material for high temperature and mechanical applications, due to its high oxidation resistance and fracture strength at elevated temperatures, excellent thermal conductivity, low coefficient of thermal expansion, and high hardness [1]. Values of the main properties of commercial reaction-sintered SiC [2] are shown in Table 1. Among the traditional uses of SiC there are heating elements for electrical furnaces [3] and abrasive wheels for grinding [4]. At present, SiC has become a promising material for several technological applications such as semiconductor production equipment parts, cooling elements in nuclear reactors, optical mirror devices in space, etc. [2, 5].

Recently, porous SiC ceramics have been a focus of attention due to the fact that porous ceramics are widely used in many areas such as filters, catalyst supports, heat exchangers, electrodes, sensors and so on [6, 7]. Routes for producing this type of ceramic products are, for example, heating preforms of SiC powder bonded with a polymer as polycarbosilane [8] or heating preforms consisting of a mix of SiC, Al_2O_3, and graphite [9].

The use of vegetal material as precursor is another route that has been recently established to synthesize porous SiC-based ceramics [10]. Among the used precursors are bamboo [11], rice husk [12], cotton [13], and wood [10, 14].

Table 1. Properties of commercial SiC obtained by reaction sintering [2].

Density, Mg/m^3	2.9
Bending strength, MPa	300
Young's modulus, MPa	310
Fracture toughness, MPa·m$^{0.5}$	2.0
Hardness (HV)	1600
Thermal conductivity, W/(m·K)	120
Specific heat capacity, 10^2 J/(kg·K)	5.8
Thermal expansion, 10^6/K	3.9

Wood is a cellular material whose morphology has been naturally optimized making it an interesting raw material for structural ceramics with tailored physical and mechanical properties. Although it has been shown that the mechanical properties of biomorphic SiC obtained from wood are a function of pore size distribution and pore orientation in addition to porosity [14, 15], the critical factor in ensuring good mechanical properties at high temperature is the amount of unreacted residual C: this amount must be as low as possible [16].

The purpose of this work was to determine the electrical conductivity of biomorphic SiC/Si composites obtained from pine and beech wood.

2. Experimental

Firstly, 20 mm diameter and 70 mm long cylindrical preforms of pine and beech wood with densities of 0.55 g/cm^{-3} and 0.71 g/cm^{-3}, respectively, were carbonized in an electrically heated tube furnace which

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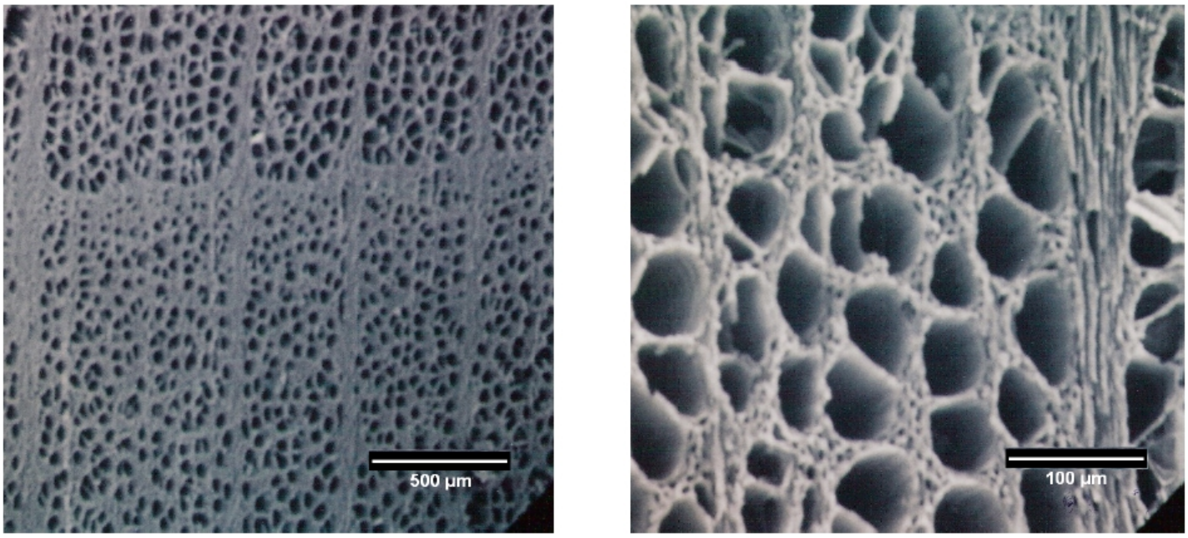

Fig. 1 (colour online). Morphology of carbon template obtained from pine wood.

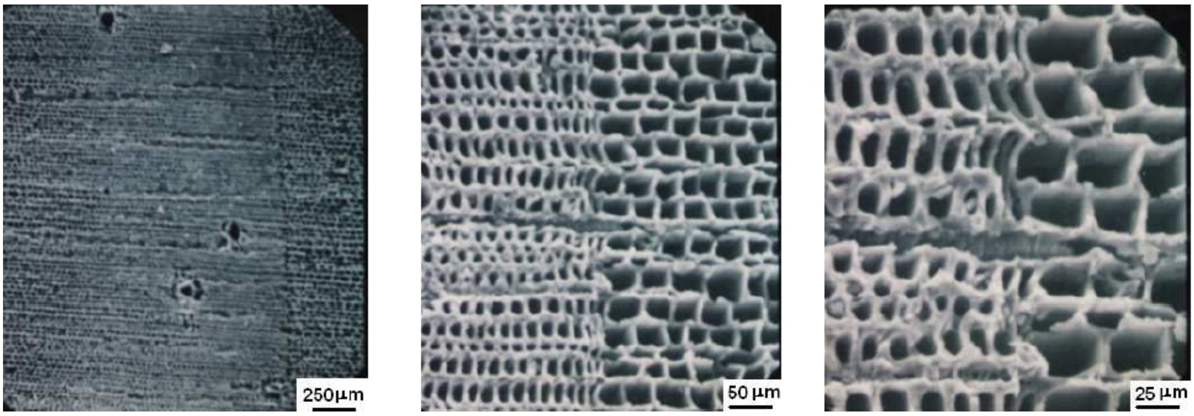

Fig. 2 (colour online). Morphology of carbon template obtained from beech wood.

was continuously flushed with nitrogen. The longitudinal direction of each preform was parallel to the plant growth axis. The furnace was heated at a rate of about 4 °C/min from room temperature to 600 °C and from 600 to 1050 °C at a rate of 30 °C/min. The peak temperature was held for 2 h, and then the samples were cooled in the furnace (about 10 °C/min).

The obtained carbon templates were infiltrated with liquid Si. For the infiltration, an electrical furnace, a graphite crucible, and a vacuum atmosphere (10^{-3} – 10^{-4} Torr) were used. Considering that the crucible was also of carbon (graphite) the amount of silicon put into the crucible exceeded in about 100 and 200% the stoichiometric amount for transforming all template's carbon into SiC. The furnace was heated at a rate of 10 °C/min from room temperature to 1200 °C, and from 1200 to 1600 °C at a rate of 100 °C/min. To produce the corresponding carbothermal reaction, the fur-

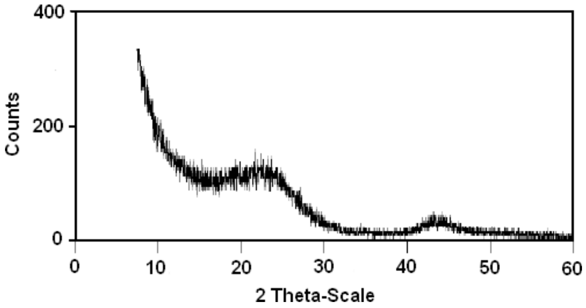

Fig. 3. XRD-pattern of carbon obtained from pine wood.

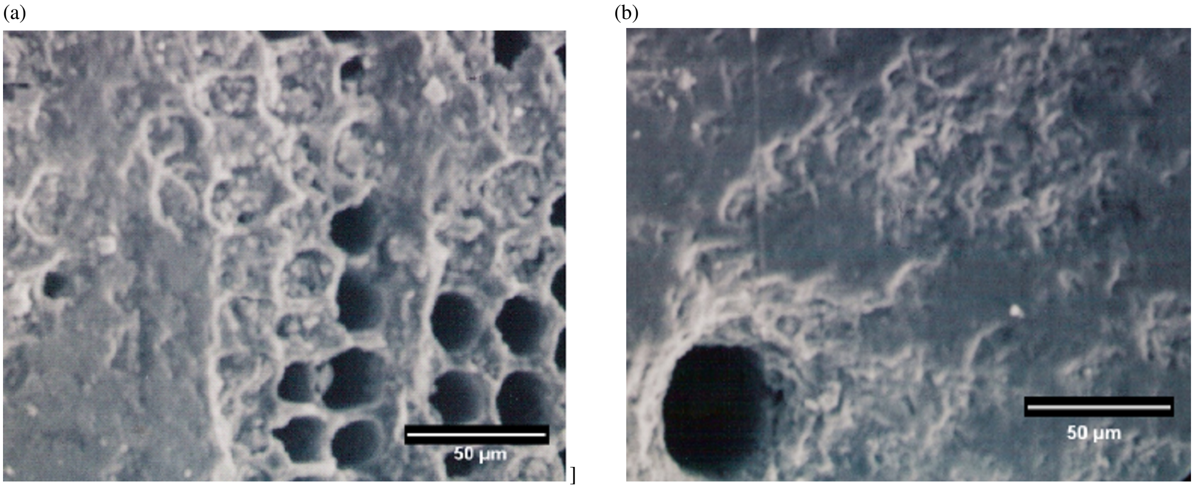

Fig. 4 (colour online). Siliconized sample obtained from pine wood: a) P1, b) P2.

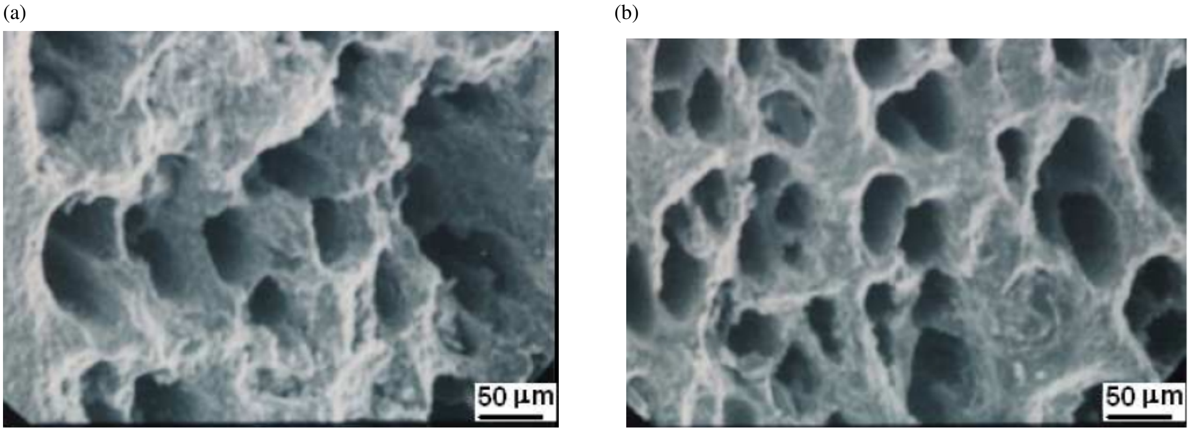

Fig. 5 (colour online). Siliconized sample obtained from beech wood: a) B1, b) B2.

nace temperature was held at 1600 °C for 2 h. The samples were then cooled in the furnace (about 16 °C/min).

The electrical conductivity of the obtained SiC/Si samples (parallel to plant growth axis), was calculated by using Ohm's law. The samples (12.2 – 12.9 mm diameter, 20.6 – 23.7 mm long) were connected to a d. c. power unit by means of copper contacts cooled by water. The electrical current and the inter-contact voltage were simultaneously measured for different temperature values of the central zone of each sample.

3. Results and Discussion

3.1. Carbon Templates

In Figures 1 and 2, the morphology of the carbon templates obtained after wood pyrolizing is shown. For the pine and beech carbon templates the density was 0.41 g/cm^{-3} and 0.54 g/cm^{-3} and the calculated porosity (by micrographic analysis) 56% and 44%, respectively.

As shown in the X-ray dosimetry (XRD) pattern of Figure 3, the template's carbon was an amorphous carbon. Since the density of compact amorphous carbon is 2 – 2.3 g/cm^3 [17] and taking into account the density and porosity values of the carbon templates mentioned above, the obtained amorphous carbon was not compact but microporous

3.2. Siliconized and Carbothermally Treated Samples

The volume of the carbon template did not change with the siliconizing and carbothermal process. There-

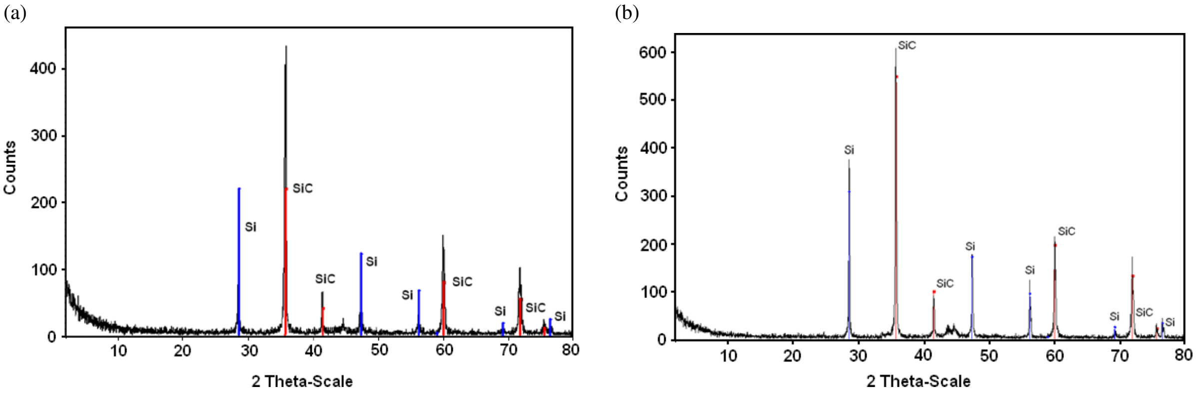

Fig. 6 (colour online). XRD-pattern of siliconized samples: a) P1, b) B1.

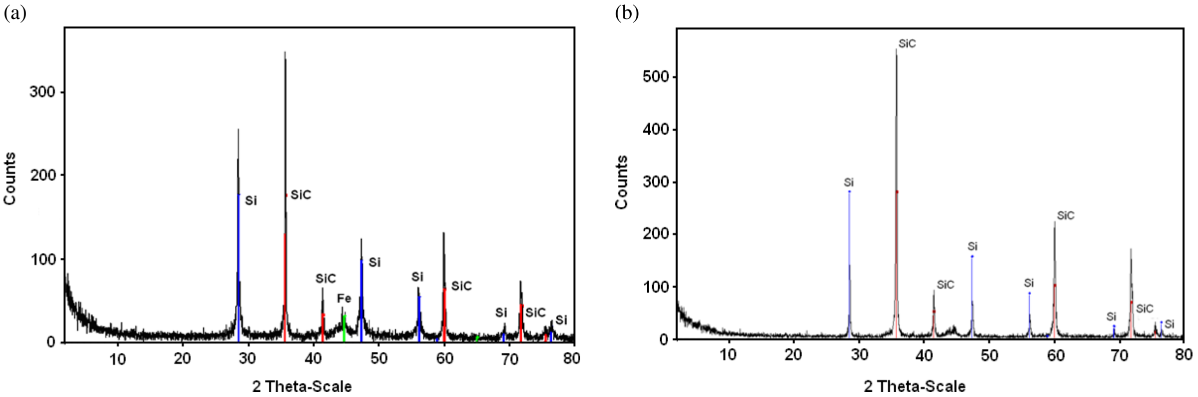

Fig. 7 (colour online). XRD-pattern of siliconized samples: a) P2, b) B2.

fore, if the infiltrated silicon had been the amount for transforming the carbon template in a sample of only SiC, the density would have been for pine 1.37 g/cm^3 and for beech 1.80 g/cm^3. However, due to the silicon excess the resulting density values were for pine (P) 1.81 (P1) and 2.57 (P2) g/cm^3 and for beech (B) 2.12 (B1) and 2.55 (B2) g/cm^3. Consequently, P2 was the sample with the greater excess of silicon.

In Figures 4 and 5, the morphology of the siliconized and carbothermally treated samples is shown. In the sample with the greater excess of silicon (P2) only the greater pores were not filled with silicon. In the other samples, the excess of silicon would have mainly filled the microporous of amorphous carbon.

In Figures 6 and 7, the XRD patterns for the siliconized and carbothermally treated samples are shown. Due to the excess of Si into the crucible in all patterns carbon peaks did not appear and only SiC and Si were detected

3.3. Electrical Conductivity

In Figure 8, the electrical conductivity values of all treated samples are shown as a function of temperature. In all cases, the electrical conductivity increased with

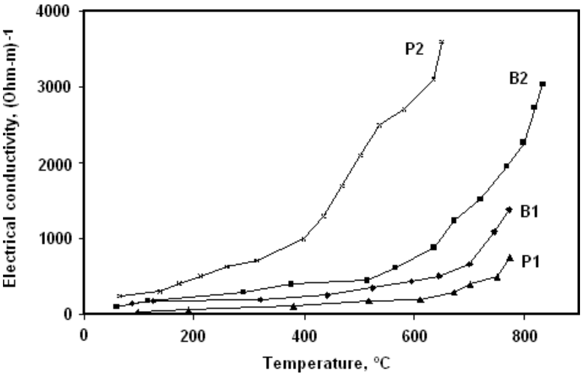

Fig. 8. Influence of temperature and silicon content on the electrical conductivity.

Table 2. Electrical conductivity values.

Temperature	Electrical conductivity, $(\Omega{\cdot}\mathrm{m})^{-1}$			
°C	P1	B1	Porous SiC/C composite sintered at 1600 °C with oxidation [20]	2D SEP, Hi Nicalon [21]
100	45	160	110	260
300	90	195	180	320
500	170	325	250	390
700	400	665	400	465

the temperature. This was the expected trend, due to the semiconductor character of both SiC and Si [18–23].

In addition, in the same Figure 8 is shown that the electrical conductivity of the SiC/Si composites increased also with the silicon content. This result can be explained by the strong influence of the temperature on the silicon conductivity. In SiC-based materials, with increasing temperature, electrical conductivity stays fairly constant and starts to increase at about 400 °C [22]. In the case of silicon, electrical conductivity at 400 °C has about twice the value at room temperature [23].

On the other hand, although the density values of sample P2 and B2 were quite similar, Figure 8 shows that the electrical conductivity of sample P2 was quite greater than that of sample B2. This result can be explained by the amount of silicon in sample P2: in P2 the excess of silicon was 1.20 g/cm^3 while in B2 the excess was 0.75 g/cm^3.

In the case of samples containing smaller amounts of silicon (P1, 0.44 g/cm^3; B1, 0.32 g/cm^3), the obtained electrical conductivity values were in the range of the values shown by other authors for some SiC composites and fibers [20, 21]. In Table 2, some of those values are given.

4. Conclusions

In this work, pine and beech wood preforms were first pyrolized and then infiltrated with molten silicon for obtaining SiC/Si composites. As expected, the electrical conductivity of these composites increased with temperature. In general, for a particular type of wood, the conductivity increased also with the silicon content. The conductivity of composites having a great amount of silicon was strongly influenced by the temperature. Conductivity of SiC/Si composites having an amount of unreacted silicon less than 0.5 g/cm^3 was similar to that of some other SiC composites and fibers.

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