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Evaluation of the Mechanical Behavior of Biomorphic Silicon Carbide Derived From Low-Density Peruvian Woods

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Abstract – Low-density Peruvian woods (tornillo and bolaina) were used as raw material for the manufacture of biomorphic silicon carbide. The plant precursors were physically-mechanically characterized and then pyrolyzed at 900 ° C in an argon atmosphere to obtain carbon templates, which were then infiltrated with metallic silicon to obtain silicon carbide with mimicked microstructures. The values found for moisture absorption, basic density and average mechanical strength in uniaxial compression were 6.51%, 0.49 g/cm^3 and 42.5 MPa, respectively, for the tornillo and 6.99%, 0.42 g/cm^3 and 41.5 MPa, respectively, for the bolaina.

Samples of biomorphic SiC derived from tornillo and bolaina presented a homogeneous and porous microstructure, the phases of SiC, Si and remaining carbon could be clearly identified. The mechanical results of the SiC samples studied showed high dispersion, with respect to the maximum resistance values, which ranged between 194 and 440 MPa for the tornillo -derived SiC and between 30 and 77 MPa for the bolaina -derived SiC.

***Keywords*:** silicon carbide, mechanical resistance, low-density wood, bolaina, tornillo, biomorphic

1. Introduction

Silicon Carbide is an advanced ceramic material widely used in industries such as high temperature processing, electronics, aerospace, abrasive treatment, engineering and armor (1-4); mainly due to its excellent properties of creep resistance, chemical stability, oxidation resistance, flexural strength and toughness at ambient and high temperatures.

Various investigations have focused on the manufacture and mechanical characterization of biomorphic SiC made from wood cellulose precursors. Currently one of the most promising methods for obtaining biomorphic carbide is the reactive infiltration of metallic silicon in a porous carbon preform due to its methodology being environmentally friendly, scalable and energy saving (5-6).

On the other hand, Peru is a country with a mega diverse flora that registers 4618 timber species, most of the low-density timber species have high strength, rigidity, tenacity, resistance to damage at micro and macro scales with a unique cellular structure, additionally It is a sustainable and renewable resource, which is why it becomes a promising resource for the production of biomorphic carbides, various investigations have focused on the use of low-density timber preforms because they can contain a large amount of Si during the infiltration processes of Si (7-13).

Therefore, the present study aims to take advantage of low-density Peruvian timber species for the manufacture of biomorphic carbides.

2. Materials and Methods

After conducting a brief diagnosis of the reality of the timber industry in Peru, it was determined that the tornillo and the bolaina are commercial, abundant and representative woods within the group of low-density Peruvian timber species. In this work, the selected woods were characterized by moisture absorption techniques, basic density that is used to calculate the dry mass of the wood that it has in volume in green (the Peruvian standard NTP 251.011 2014: Determination of density of wood, was used), optical microscopy (they were performed in an AMSCOPE brand optical microscope (50X - 500X), model ME320B-PZ, USA), and uniaxial compression (it was carried out in a universal testing machine brand MICROTEST, model EM1/50/FR, Spain). Both types of wood were subjected to thermal processes of (i) pyrolysis in an inert atmosphere (900°C and 0.5 hours of isotherm), following the thermal cycle of Fig. 1(a) and (ii) reactive infiltration with metallic silicon at temperatures of 1550 °C and in a vacuum atmosphere (Fig.1(b)). It should be noted that for all the SiC samples manufactured, 50% silicon was used in excess, with respect to the stoichiometric amount of the SiC molecule.

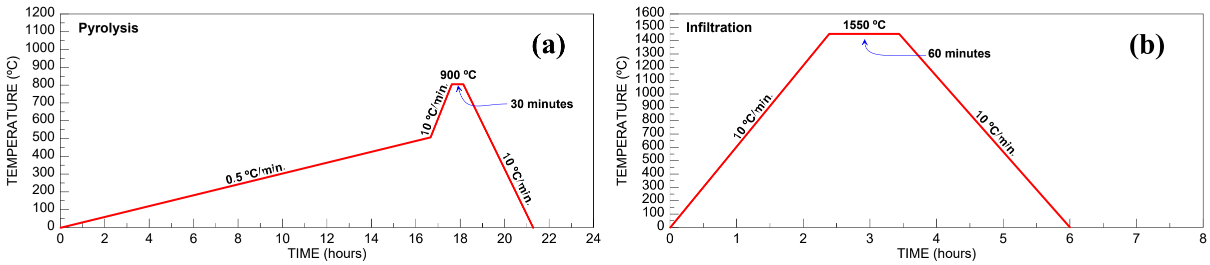

Fig. 1: Thermal profiles for the processes of (a) pyrolysis and (b) reactive infiltration.

The mechanical characterization of the SiC samples was carried out at a constant compression rate of 0.05 mm/min., in air atmosphere and at room temperature. The samples for the compression tests consisted of parallelepipeds of 3x3x6 mm^3 and were obtained by cuts with a diamond edge disc, made on the largest samples of infiltrated SiC. Force and displacement data were obtained from the mechanical tests, which were then converted and analyzed into stress vs. deformation.

3. Results and Discussion

3.1. Physical, Microstructural and Mechanical Characterization for Tornillo and Bolaina

The average basic density for the precursor woods was 0.49 and 0.42 g/cm^3 for the tornillo and bolaina, respectively. Fig. 2 shows carbon optical microscopy micrographs of the two types of selected woods. Both surfaces observed are of the cross-section (with respect to the growth direction of the tree) and are clearly defined. The microstructure of the tornillo and bolaina samples consist of a single continuous phase, with the presence of evenly distributed pores in darker contrast. With the support of the digital image processor ImageJ, the diameters of the largest porosities of both samples were determined. Resulting in an average porosity diameter for the bolaina of 155.8 µm and for tornillo of 221.6 µm.

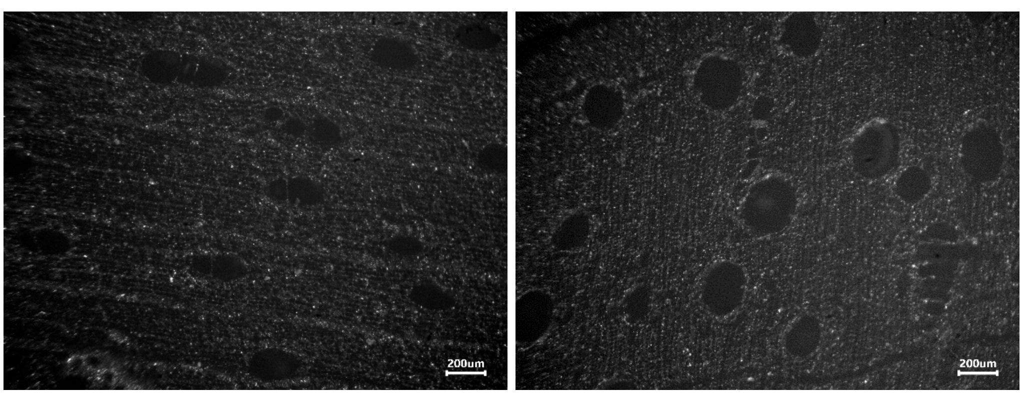

Fig. 2: Micrographs of the carbon cross section obtained by optical microscopy from samples (a) bolaina and (b) tornillo

Fig. 3 shows stress vs. deformation for tornillo (Fig. 3(a)) and bolaina (Fig. 3(b)) samples in the direction parallel to the fibers. The mechanical results obtained from the precursor woods show similar mechanical strengths for both types of wood with maximum strength values of between 38 and 47 MPa for the screw and between 35 and 48 MPa for the bolaina. It is worth noting a slight greater rigidity in the bolaina, with respect to the tornillo, and greater deformations in the tornillo compared to the bolaina.

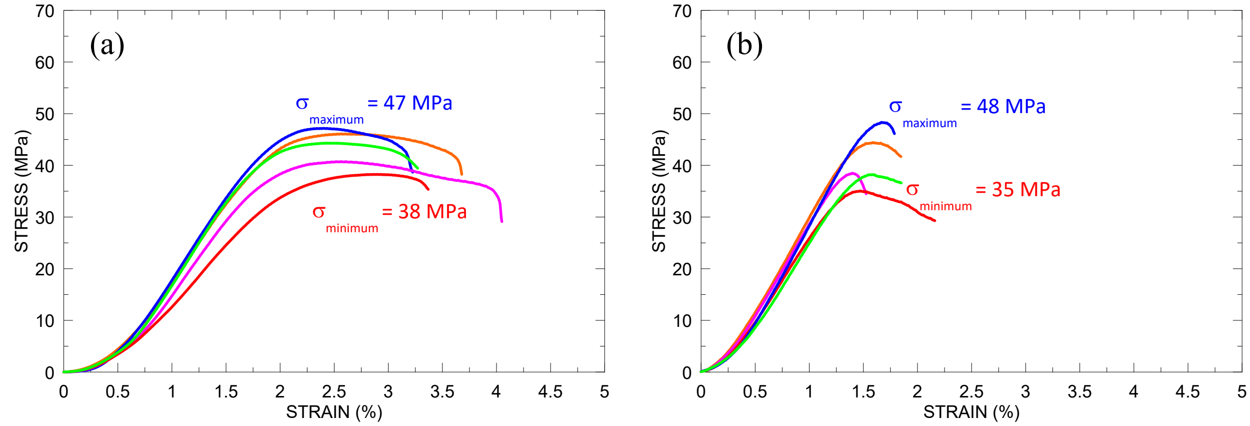

Fig. 3: Stress vs. strain for (a) tornillo wood and (b) bolaina wood tested at constant compression rate and at room temperature

3.2. Mechanical Characterization Sic Derived From Tornillo and Bolaina

Fig. 4 presents stress vs. strain curves for silicon carbide derived from tornillo wood (Fig. 4(a)) and bolaina wood (Fig. 4(b)). In both groupings of curves, the low repeatability of maximum resistance results could be evidenced, varying from 194 to 440 MPa for the case of tornillo SiC and from 30 to 77 MPa for bolaina SiC. This result suggests considering non-structural applications for the manufactured materials, considering the use of tornillo SiC in applications that demand mechanical strengths less than 190 MPa and applications with mechanical requirements less than 30 MPa for SiC derived from bolaina. It was also possible to observe greater deformations in screw SiC, with respect to bolaina SiC.

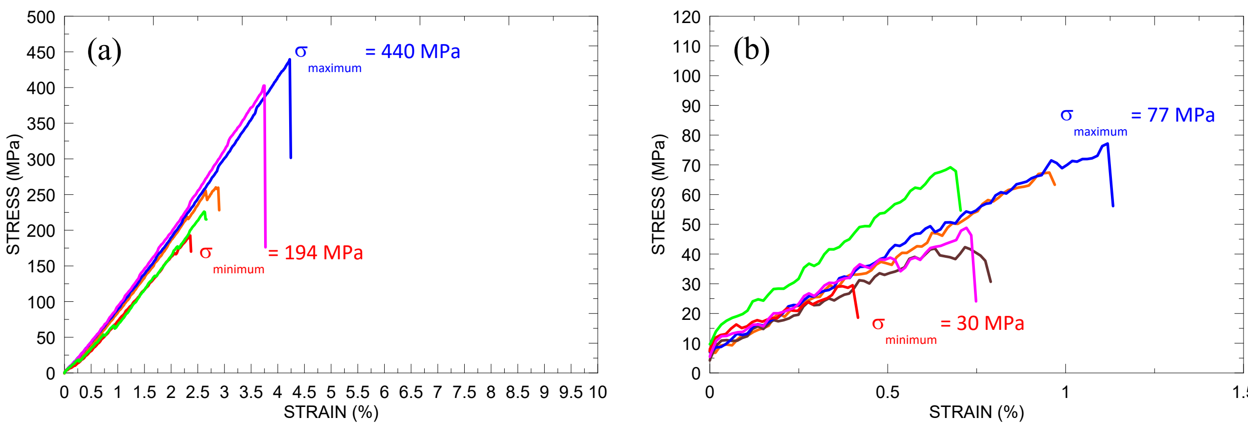

Fig. 4. Stress vs. strain for biomorphic SiC derived from (a) tornillo wood and (b) bolaina wood obtained in uniaxial compression and at room temperature

4. Conclusions

SiC materials have been successfully manufactured from low density wood precursors (tornillo and bolaina), following the procedures established in the literature on pyrolysis of wood in an inert atmosphere followed by reactive infiltration of metallic silicon in carbon preforms.

The basic density values found for the tornillo and bolaina were 0.49 and 0.42 g/cm^3, respectively, these being very close to each other. Both species of wood are considered low-density commercial woods.

The microstructures found in the wood samples revealed the presence of a single phase made up of short fibers and well distributed rounded porosities.

The average large porosity diameter of bolaina and tornillo were 155.8 μm and 221.6 μm, respectively. This characteristic is key to the infiltration process in the preform, since the smaller the pore size, its obstruction by the formation of SiC is more feasible.

The maximum mechanical strengths in uniaxial compression, obtained in the direction parallel to the fibers, showed very similar values for the tornillo and the bolaina, however, a larger plastic region could be observed in the tornillo, compared to what was observed in the bolaina.

It was not possible to show repeatability in the uniaxial compression tests performed on SiC samples derived from tornillo and bolaina, which suggests that the SiC materials studied in this work are intended for non-structural applications.

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