ALUMINIUM MATRIX COMPOSITE WITH SUGARCANE BAGASSE ASH AS REINFORCEMENT MATERIAL

COMPÓSITO DE MATRIZ DE ALUMINIO CON CENIZA DE BAGAZO DE CAÑA DE AZÚCAR COMO MATERIAL DE REFUERZO

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The results of the characterization of the Sugarcane Bagasse Ash from the co-generator boiler (SCBAB) of a Cuban sugar mill, obtained in previous works are offered. Aluminum Matrix composites (AMCs) samples were fabricated employing powder metallurgy technique.
The comparative study of the Al-SCBAB composite with respect to the non-reinforced matrix showed an increment in the hardness of the AMCs reinforced with SCBAB as compared with the non-reinforced matrix. Finally, it was concluded that the SCBAB has good properties for its use as reinforcing material in AMCs.

Se ofrecen los resultados de la caracterización de la ceniza de bagazo de caña de azúcar procedente de la caldera del turbogenerador de un central azucarero obtenidos en trabajos precedentes. Empleando la técnica de pulvimetalurgia se fabricaron las muestras del composite.
El estudio comparativo del compuesto con respecto a la matriz no reforzada mostró un incremento en la dureza del composite reforzado con la ceniza con respecto a la matriz no reforzada. Finalmente, se concluyó que la ceniza tiene buenas propiedades para su uso como material de refuerzo en composite de matriz de aluminio.

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I. INTRODUCTION

A composite is defined as the material which has two or more distinct constituents: the matrix and the reinforcement materials. The composite is distinguished by its bulk properties, which are significantly different from those of any of the constituents present in this system [1, 2]. The reinforcement is a discrete constituent distributed into the continuous matrix. However, as described by Sharanabasappa and Motgi [1], many common materials also have a small amount of a dispersed constituent in their structure and they are not considered as composite materials because their properties are similar to those of their base constituents. In previous definitions and analysis, the term ”phase”has been replaced by “component” or “constituent” due to a recent point of view expressed by Fakirov [3], whom has indicated the incorrect practice in the composite community of using the term “phase” instead of “component” when dealing with composite materials.

The composite materials are usually classified based on the physical or chemical nature of the matrix [2], e.g., polymer-matrix, metal-matrix and ceramic composites. There are some reports [2, 4–8] that described both, the emergence and present time of the Metal Matrix Composite (MMCs). The MMCs hold significantly higher properties when compared to non-reinforced same materials, and can be widely applied in various industrial sectors. However, as explained [6, 7, 9] their current usage apparently have been limited due to their relatively high production cost.

According to Alaneme [10], the Aluminium Matrix Composite (AMCs) are the most versatile of the MMCs because of a number of factors, whose advantages include ease of processing, relatively low cost of Al matrices in comparison with other competing metal matrices (Cu, Ti, Mg), good combination of physical and mechanical properties, good properties at high temperature and thermal management capability, excellent tribological properties, and reasonable corrosion resistance [4, 9–14]. This same author, referring to Miracle [4] explains that it is for these reasons that AMCs have found application in diverse technological areas and their influence as an engineering material is expected to continue to rise in the years ahead. Of course, in the base of this is found, as described by Kumar and Purohit [15] the fact that Aluminium is the most abundant metal and the third most abundant chemical element in the earth’s crust. In addition, Aluminium and Aluminium alloys have lightweight and a very desirable combination of properties, along with the ease with which of the most pieces of a great variety shapes and dimensions can be manufactured.

In previous investigations, it was shown that there is a growing interest in exploring low-cost options for the development of AMCs with the hope of still maintaining their high performance levels in service applications [2, 4, 10, 12] and [16]. At the same time, according with Lancaster, Lung and Sunjan [17] at present the application of agro-industrial wastes in AMCs has been getting more attention because of that the ashes of this wastes can be used as reinforce particles in metal matrices to enhance their strength properties. In addition, by applying these agro-industrial wastes in useful ways not only save the manufacturing cost of products but also reduce pollution on the environment [17, 18]. In recent years, several studies have been made [10,16,22] about AMCs that use Rice husk ash, Bamboo leaf ash, Coconut shell ash, Palm oil fuel ash or Bagasse ash among other agro-industrial waste materials as reinforcements. In Cuba, big amounts of sugar cane are processed, generating high volumes of solid waste. A part of these wastes are employed in animal feeding and other parts are disposed and burnt in open landfills, with its negative impact on the environment. Bagasse is an important by-product of the sugar cane industry and most of it is burned to produce steam and generate electricity in co-generators at sugar factories. Sugar cane bagasse ash is the result from the bagasse combustion in the boiler, and is a solid waste too. However, although there are international reports of the successful use of different cellulose materials ashes and particularly of sugar cane bagasse ash like reinforcement materials in MMCs (cited above); it was not found any report that refers to the employment of the Cuban sugar cane bagasse ash with this end.

The present work is an effort in considering the potentials of sugar cane bagasse ash from boiler of co-generation plant at the sugar factories (SCBAB) for development of low-cost AMCs. In addition, the morphology and hardness of AMCs reinforced with a level of 4 % in weigh of SCBAB was studied.

II. MATERIALS AND METHODS

II.1. Ash Characterization

The sugar cane bagasse ash (SCBA) used was collected directly from the boiler of the co-generator plant (turbo generator) at the "Luis Arcos Bergnes" sugar factory in Camajuani city, province of Villa Clara, Cuba. In the turbo generator boiler, the combustion process is not controlled. The obtained ash has a gray color. The SCBAB was milled in a ceramic ball mill during 60 minutes at rotational speed of 150 rpm and sieved below 150 μm. The particle size distribution was determined using a laser diffraction particle size analyzer (Malvern Mastersizer Particle Size Analyzer and Mastersizer Software long bed Version 2.19) in liquid mode with deionizer water as dispersant and ultrasound agitation for 60 s.

The chemical compositions of the obtained SCBAB was determined by X-Ray Fluorescence Spectrometry (XRF), using Phillips PW1400 (tube of Rh, 30 kV, 60 mA) Axios XRF spectrometer.

The mineralogical composition of the SCBAB was studied by X-Ray Diffraction (XRD), employing Phillips MPD 1880 spectrometer made in Holland. The radiation used was Cu Kα. The identification of the crystalline phases was carried out by comparison of the experimental data with the database PAN-ICSD (PANanalytical Inorganic Crystal Structure Database).

The morphological study of this ash was carried out by SEM, using a FEI Quanta 600 FEG scanning electron microscope.

II.2. Specimen preparation

The composite specimens have been prepared employing the powder metallurgy technique. Two kinds of samples were manufactured. The first class of samples corresponds to the Aluminum matrix composite reinforced with SCBAB (Al-SCBAB Composite) and the second kind to a non-reinforced Aluminum matrix.

A powder form 99.5 % reagent grade Aluminium was selected as the metal matrix. The Aluminium powder was preconditioned prior to adding the SCBAB and mixing powders. This preconditioning procedure involves drying the Aluminium powder in a furnace with atmospheric nitrogen and temperature of 450degC. The drying took place until no further change in mass was observed. The procedure normally required around 4 hours to remove the associated water molecules present in the hydrated oxide film of the Aluminium powder particles to avoid subsequent gas porosity into the composite. The Aluminium powder was then cooled at room temperature in desiccators with activated zeolite.

In the same way, the SCBAB was preconditioned prior to mixture with the Aluminium powder. The SCBAB was dried in a furnace at 250degC of temperature and cooled at room temperature in desiccators with activated zeolite.

The SCBAB was added to the Aluminium powder up to a level of 4 % in weight and then the powders were mixed in a stirring- mixer during one hour until a homogeneous mixture of powders was achieved.

The mixed powders were compacted axially at cold state in stainless steel cylindrical dies of (19.60±0.01) mm and (46.91±0.01) mm of diameter and length respectively in the laboratory vertical unidirectional mechanic press. The obtained compact specimens have similar dimensions and density. The same way it proceeded with non-reinforced matrix (comparative sample test). In both cases, the applied pressure was 10 tn.

The compact specimens were subjected to the sintered process in a furnace at 600degC. The sintering process was carried out under constant flow of nitrogen. The heating of the furnace was started after that the samples have been place inside it. The temperature of 600degC was reached at about 60 minutes. Later, once the sintering process is completed, the compact specimens were removed from the furnace and allowed to cool in desiccators with activated zeolite.

Finally, the compact specimens was extruded and cylindrical bars with diameter of (10±0.01) mm and length of (20±0.01) mm were obtained as the end composite sample.

Five groups of ten specimens of each type were submitted to the Vickers hardness test and, one of each type was allocated for morphological study by optic microscopy.

Hardness is a measure of how the solid matter can withstand pressures with objects of various shapes when acting on it with a permanent force for a given time. There are three types of tests used for hardness measurement. However, in the present work only the Vickers hardness test was considered. Vickers hardness measurements were carried out in order to investigate the influence of SCBAB on the matrix hardness. Hardness measurement was carried out using a Microhardness tester Shimadzu Corporation made in Japan with a measurement uncertainty of 3 %. The load applied was 25 g for 10 seconds.

Before testing, specimen surfaces were polished using emery papers of 1000 mesh. Finally, the trials were made on five specimens of each type (five Al-SCBAB composite and five comparative sample tests.

The morphological study of both, the Al-SCBAB composite and the non-reinforced Aluminium matrix was made using a Novel optic microscope from Nanjing Jiangnan NOVEL Optics Co., Ltd. The microstructure images were acquired by a camera, high-sensitivity Yuva mark of 1.3 MPixel. The camera was coupled to both the ocular of the microscope and a computer with specialized software for both the images acquisition. Image digital processing was made with the software ImageJ version 1.43 cite[25].

Before testing, specimen flat surfaces were polished. First, the flat surfaces of the cylindrical discs were devastated using a series of abrasive papers of different mesh and then polished with diamond paste.

III. RESULTS AND DISCUSSION

III.1. Ash characterization results

Ash characterization was made in previous work and its results reported by Villar-Cociña et al. [23] and Pino-Rivero et al. [24]. The fundamental results obtained from these previous works can be summarized below:

(a) The SCBA particles have irregular shape and varying size distribution. The higher percentage have an diameter size between 10 and 100 microns, with an average diameter size of 34.97 μm.

(b) The SCBAB is basically formed by silica in concentrations of about 80 %.

(c) The Cristobalite and tridymite are the principal crystalline phases present in the SCBAB. These results makes the ash studied an excellent candidate as reinforcement material in metal matrix composites.

III.2. Comparative study of morphology and hardness of Al-SCBAB composite and its non-reinforced matrix

Morphological aspect of Al-SCBAB composite and its non-reinforced matrix

Typical AMC microstructures are represented in Figure 1. In the microphotographs a change of appearance of the composite with respect to the unreinforced matrix can be appreciated.

The above microphotograph shows that the SCBAB is near uniformly distributed in the metal matrix and good bonding between Aluminium matrix and this reinforcement are achieved. Most notably, SCBAB and Aluminium are practically uniformly distributed along the specimen, i.e., the negligible variations of local fractions that can be appreciated, perhaps due to the inhomogeneity of the preform, which can be avoided by sufficient mixing of the Aluminium powder and SCBAB.

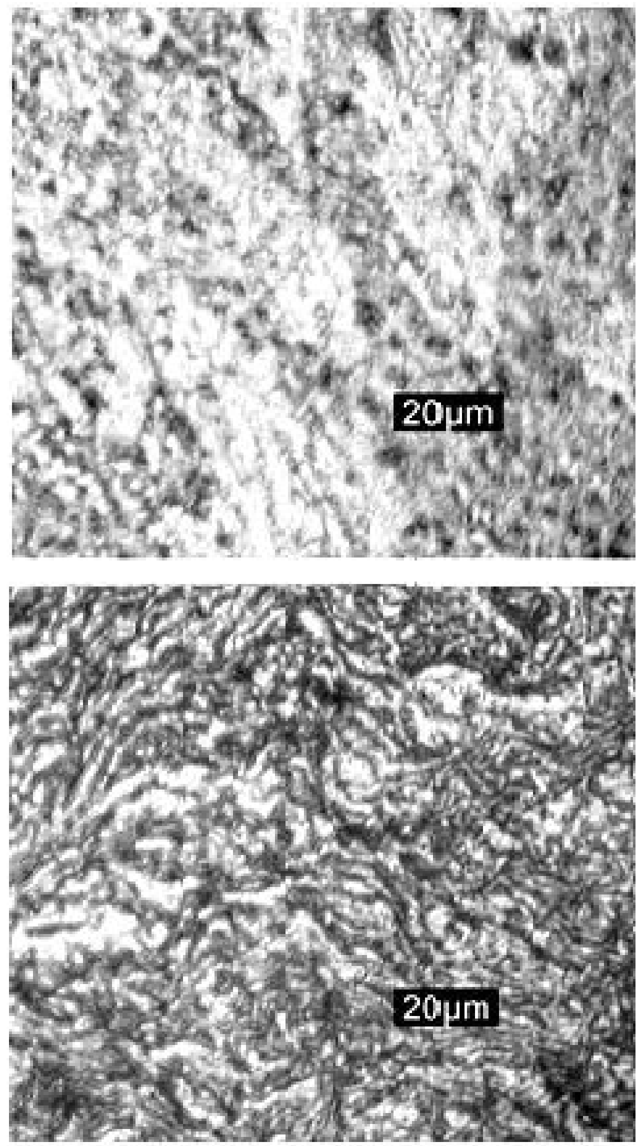

Figure 1. Optic microphotograph of Al-SCBAB composite specimen (above) and the non-reinforced matrix sample (down).

Both images were analyzed using image digital processing techniques with the software ImageJ version 1.43. This analysis allowed not only to improve the quality of the original images, but also to determine the fraction of grain area corresponding to each sample, which was 4.9 and 6.7 for the composite and the non-reinforced matrix, respectively. This is an indication that the grains of the composite have a lower Feret diameter [26], and at the same time, according to the Hall-Petch equation's, a higher hardness of the composite [27]. Then, during the composite conforming process and its sintering at 600degC of temperature, the hardening of the material was produced by reduction of the grain size.

Hardness of Al/SCBAB composite and its unreinforced matrix

Table II shows the results of the Vickers hardness test.

Table 1. Hardness of the different groups of Al-SCBAB composite and its non-reinforced matrix.

Groups	Un-reinforced Matrix	Al-SCBAB Composite
1	86.5	92.3
2	87.5	93.5
3	89.0	93.5
4	89.0	93.9
5	92.5	96.5
Mean	88.9	93.94

It can be appreciated that the mean hardness increases from 88.9 HV for non-reinforced matrix to 93.94 HV for the Al-SCBAB composite, i.e., for the Aluminium with addition of sugarcane bagasse ash from boiler of the co-generator of the Cuban sugar factory. This hardness increment is in the order of that reported by other researchers [10,17,18,28,29] for composites of similar nature. However, the relative increase in hardness of the composite compared with its similar non-reinforced is relatively low, only of at 5.67 percent. At the same time, as mentioned before, the uncertainty in the measurement of this property was 3 %, so that the quantity measured is in the same order of the instrument uncertainty and only 2.67 units above it.

Through statistical tests (Pair Simple t test, ANOVA and others) it can be verified that the mean hardness of the composite significantly increased compared to the non-reinforced matrix. The SPSS software and the Pair Simple t test were employed for statistical analysis. As the null hypothesis it was established that the difference between the mean hardness for the non-reinforced matrix and Al-SCBAB composite is equal or greater than zero, and as alternative hypothesis that this difference is less than zero. It was obtained that for a confidence level of 0.05, difference between means is significant.

The hardness values increased possibly due to the presence of the hard ceramic phase of the bagasse ash (cristobalite and tridymite) and its interaction with the ductile matrix. As explained by Aigbodion and co-workers [22] referred by Lancaster, Lung and Sujan [17] as far as hardening behavior of the composites is concerned, the particle addition in the matrix alloy increases the strain energy in the periphery of the particles in the matrix, and these tendencies may be due to the formation of dislocations at the boundary of the ceramic particles by the difference in the thermo-expansion coefficient between the matrix and ceramic particles.

For AMCs that employ different agro-industrial wastes as reinforcement materials, it has been reported that hardness increases until certain limit when ash weight ratios with a silica high content increases [10, 17, 18, 20, 28, 29]. Thus, it is valid to assume that in this case the same can be observed. The hardness behavior together with other mechanical properties and the wear with SCBAB percentage increase is a research aim for the future.

IV. CONCLUSIONS

The basic conclusions that can be drawn through this research work are summarized below:

- A level of 4 % in weight of SCBAB in AMCs acts favorably as reinforcing material. In particular, it produces a significant increase of the hardness from 88.9 HV for the non-reinforced matrix to 93.94 HV for the matrix with addition of this ash.
- To sum up, the SCBAB studied shows good properties (ceramic materials-like), which makes them a good reinforcement material for AMCs.

Future studies will include both, the mechanical properties and wear behavior of AMCs reinforced with varied weight ratios of SCBAB.

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