ADVANCED CERAMICS FOR SOLAR ABSORBERS

García-Ten, F.J.[1]; Lorente-Ayza, M-M.[1]; Vicent, M.[1]; Planelles-Aragó, J.[1]

(1) Instituto de Tecnología Cerámica (ITC). Asociación de Investigación de las Industrias Cerámicas (AICE).
Campus Universitari Riu Sec. Av. Vicent Sos Baynat s/n. 12006. Castelló. Spain.

***E-mail**: javier.garcia@itc.uji.es*

EUROMAT 2021
EUROPEAN CONGRESS AND EXHIBITION
ON ADVANCED MATERIALS AND PROCESSES

1. INTRODUCTION

Advanced ceramics (made up of oxides, nitrides, carbides and non-silicate glass) present interesting properties, among others, thermal insulation, lightness, high specific surface area, thermal shock resistance, mechanical strength or chemical inertness. Consequently, the development of ceramics for high temperature applications has become an emerging area of research. These ceramics must exhibit certain properties including resistance to creep deformation at interfaces, chemical stability, oxidation resistance, low volatility, thermal shock resistance and enough toughness at ambient temperature.

Solar-driven thermochemical processes and other high temperature solar applications require a high concentration of solar radiation, often exceeding 100 W/cm^2. For this purpose, advanced ceramics are a good choice, since these materials are capable to withstand temperatures up to 1400ºC or higher, while remaining stable against morphological damages. Moreover, for this use, selected materials should be capable of supporting high flux densities and temperatures for thousands of cycles, as these systems operate daily with start-up and shut-down procedures.

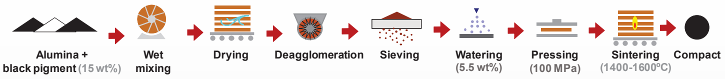
The most commonly material used in solar plants is silicon carbide (SiC). Silicon carbide is a non-oxide grey semiconductor with good sunlight absorption and high oxidation resistance, but also characterized by a high thermal emittance, the absence of spectral selectivity, a complex production technique and a high cost.

Alumina (Al_2O_3) is the most widely used technical ceramic because of its excellent performance at high temperature in aggressive environments and low cost; however, it is unsuitable for solar absorbers owing to its inherent white colour.

In the present work, different black pigments have been added to alumina to increase its absorption, determining their thermal and optical properties. Since the black pigments selected have different compositions and structures, their influence on the final properties of the mixtures has been analysed.

2. MATERIALS AND METHODS

Mixtures of alumina and black pigments have been prepared by the following route:



Materials:

- Alumina CT3000SG, provided by Almatis (www.almatis.com).
- Black pigments, provided by ITACA (www.esmalglass-itaca.com), in a proportion of 15 wt%.
- Silicon carbide Densitek15, provided by Fiven Norge (www.fiven.com) (samples provided already pressed and sintered).

Five compositions have been studied, analysing the influence of type of pigment on green and fired bulk density, open porosity, chromatic coordinates, emissivity, absorbance and conductivity at their maximum densification temperature. Maximum densification temperature has been obtained from the sintering diagram.

Table 1. Properties of black pigments used in compositions.

Pigment	BL-1	BL-2	BL-3	BL-4	BL-5
Main elements	Fe, Cr, Ni, Mn	Fe, Cr	Fe, Cr	Fe, Cr, Co	Fe, Mn
Main structure	Spinel	Solid solution	Spinel	Spinel	Solid solution
Classification	PB30	PB29	PB29	PB27	PB26

3. RESULTS

Next tables and figures summarize the results obtained. In table 2 dry properties of compacts are shown, seeing that dry bulk density increases when black pigments are added to the alumina.

Tables 3 and 4 indicates sintered properties of compacts, at maximum densification temperature, compared with properties of Densitek15 (pressed and sintered by Fiven Norge). The addition of pigment reduces the sintering temperature, obtaining samples with open porosity near zero.

Figure 1 shows thermal properties of compacts, compared with alumina and silicon carbide. The addition of black pigment increases absorbance values (comparing to alumina with no pigment), no modifying the emissivity.

Figure 2 depicts the variation of emissivity, absorbance and ratio of both with L*-coordinate (which represents the luminosity of the compact), showing a lineal dependence for absorbance and α/ε ratio.

Table 2. Dry properties of samples prepared with black pigments, compared with alumina.

Pigment	CT3000SG	BL-1	BL-2	BL-3	BL-4	BL-5
Pigment proportion (wt%)	0	15	15	15	15	15
Dry bulk density (g/cm^3)	2.24	2.39	2.43	2.51	2.47	2.41

Table 3. Sintered properties of samples prepared with black pigments, compared with alumina.

Pigment	Densitek15	CT3000SG	BL-1	BL-2	BL-3	BL-4	BL-5
Pigment proportion (wt%)	0	0	15	15	15	15	15
Temperature (ºC)	2110*	1600	1500	1550	1525	1525	1410
Bulk density (g/cm^3)	3.17	3.91	3.84	3.88	3.80	3.94	3.82
Open porosity (%)	0.0	0.7	0.0	0.2	0.4	0.1	0.1

* According to Fiven catalogues.

Table 4. Chromatic coordinates of samples prepared with black pigments, compared with alumina.

Pigment	Densitek15	CT3000SG	BL-1	BL-2	BL-3	BL-4	BL-5
Pigment proportion (wt%)	0	0	15	15	15	15	15
Temperature (ºC)	2110*	1600	1500	1550	1525	1525	1410
L*	38.6	90.9	36.3	37.1	41.8	35.9	35.3
a*	0.3	1.4	3.5	4.3	3.8	-0.1	2.1
b*	-0.1	14.2	4.5	7.3	9.8	2.7	2.6

* According to Fiven catalogues.

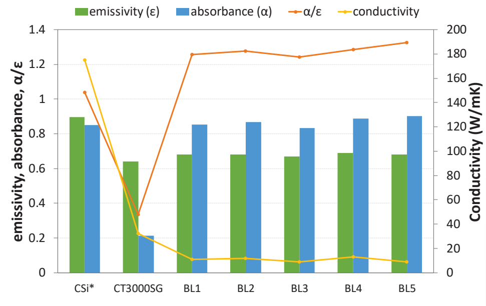


Figure 1. Emissivity, absorbance, α/ε and conductivity of samples obtained with different black pigments, compared with alumina CT3000SG and silicon carbide*.
** Values from different sources: www.goodfellow.com; www.engineeringtoolbox.com; L. Charpentier et al.*

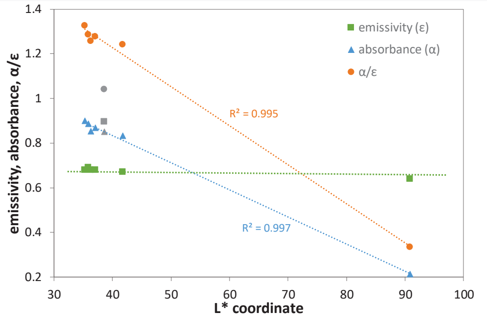


Figure 2. Variation of emissivity, absorbance and α/ε with L* coordinate of samples based on alumina CT3000SG. Bibliographic values of silicon carbide* have been added in grey.
** Values from different sources: www.engineeringtoolbox.com; L. Charpentier et al.*

4. CONCLUSIONS

- ⇒ Dry bulk density of compacts show higher values than those of alumina, partially because black pigments present higher true density (4.2-4.9 g/cm^3 vs 4.0-4.1 g/cm^3 of alumina).
- ⇒ The addition of black pigments reduces significantly the temperature necessary to reach open porosity below 0.5%.
- ⇒ L*-coordinate, which represents luminosity, decreases drastically when black pigments are added to alumina, reaching values close to those of silicon carbide L*-coordinate. The decrease depends on the type of pigment.
- ⇒ Emissivity remains practically constant when black pigments are added to alumina (0.64-0.69), being lower than those of silicon carbide (0.83-0.96).
- ⇒ Absorbance increases abruptly in compacts with black pigments (0.83-0.90), reaching similar values to those of silicon carbide (≈0.85).
- ⇒ α/ε ratio of black pigment compositions (1.24-1.33) are similar those of silicon carbide (≈1.0).
- ⇒ Absorbance and α/ε ratio presents a linear dependence with L*-coordinate, being the value of absorbance of silicon carbide consequent with this tendency.
- ⇒ In compacts with black pigment, absorbance depends on the type of pigment, which also determines L*-coordinate.

5. REFERENCES

[1] T. A. Otitoju et al. Advanced ceramic components: Materials, fabrication, and applications. Journal of Industrial and Engineering Chemistry 85 (2020) 34–65.
[2] A. Vidal, D. Martinez. An ageing protocol for testing high temperature solar materials for thermochemical applications. Solar Energy Materials & Solar Cells 212 (2020) 110572.
[3] F.A.C. Oliveira et al. Thermal resistance of solar volumetric absorbers made of mullite, brown alumina and ceria foams under concentrated solar radiation. Solar Energy Materials and Solar Cells 194 (2019) 121–129.
[4] L. Charpentier et al. Influence of the porosity of SiC on its optical properties and oxidation kinetics. AIP Conference Proceedings 2126-1 (2019), 030013.

6. ACKNOWLEDGEMENTS

This work has been carried out thanks to the project "Ceramic materials for energy applications. CERAMITECH", funded by the Generalitat Valenciana, through the Instituto Valenciano de Competitividad Empresarial (IVACE).

The collaboration of samples suppliers is gratefully acknowledged: ITACA, ALMATIS and FIVEN NORGE.