SOLAR ABSORBERS BASED ON MIXTURES OF ALUMINA AND CERAMIC PIGMENTS: INFLUENCE OF PIGMENT CONTENT

Lorente-Ayza, M-M.[1]*, García-Ten, F.J.[1], Miguel, E.[1], García-Llácer, C.[1], Planelles-Aragó, J.[1], Cañadas, I.[2], Martínez, D.[2], Rodriguez-García, J.[2]

[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.
[2] CIEMAT-Plataforma Solar de Almería. Ctra. Senés Km 4.5, 4200 Tabernas, Almería (Spain)

*** E-mail**: magda.lorente@itc.uji.es

MADRID 2022
LVIII Congreso de la Sociedad Española de Cerámica y Vidrio

1. INTRODUCTION

Volumetric absorbers used in point focus concentrating solar systems act as a heat exchanger, receiving solar radiation and reaching high temperatures. Non-oxide ceramics, especially silicon carbide, are the most commonly used materials in the manufacture of volumetric absorbers . However, SiC has some drawbacks, such as its difficulty in shaping, its relative ease of oxidation and fracture, and its high cost. However, alumina, which presents excellent thermal, mechanical and chemical resistance, is able to withstand temperatures up to 1400 ºC or higher, remaining stable against morphological changes, so it could be a suitable and lower cost alternative, if its solar absorbance is improved.

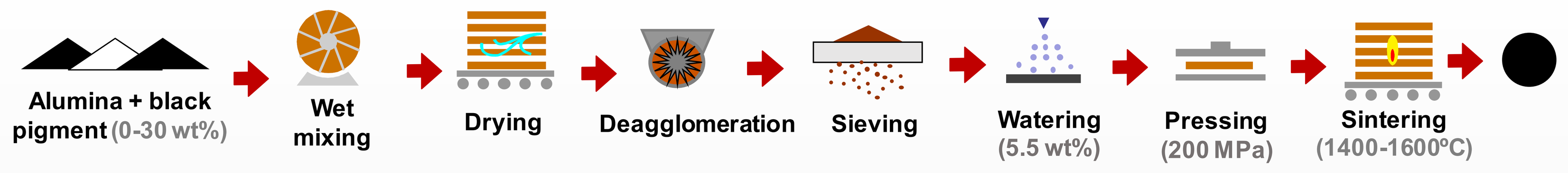
In the present work, a black pigment usually employed in the ceramic tile industry has been added to alumina in different proportions (5-30 wt%) to increase its solar absorbance. To analyse the influence of the pigment content in the compositions' behaviour at their maximum densification, the sintering diagrams (evolution of bulk density with sintering temperature) have been conducted; moreover, other properties (lineal, shrinkage, open porosity and chromatic coordinates) have also been determined at several peak temperatures.

Finally, accelerated and cycling aging thermal treatments have also been carried out to analyse the possible degradation of the ceramic compacts, both in electric and solar ovens, in a solar accelerated aging test bench. After that, the properties of the compacts have been determined again, comparing the pre and post treatment characteristics (bulk density, open porosity and chromatic coordinates).

All properties have been compared with silicon carbide and alumina.

2. MATERIALS AND METHODS

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



Materials:
- Alumina CT3000SG, provided by Almatis (www.almatis.com).
- Black pigment of Fe-Cr (solid solution) PB29, provided by ITACA (www.esmalglass-itaca.com).
- Silicon carbide Densitek15, provided by Fiven Norge (www.fiven.com) (samples provided already pressed and sintered).

Accelerated and cycling aging treatments have been conducted as follows:

⇒ Electrical aging: 24 hours at 1400ºC in an electrical kiln
⇒ Electrical cycling: heating up to 1200ºC (soaking time: 10 min), cooling <500ºC. 15 cycles in an electrical kiln
⇒ Solar accelerated: high frequency ageing cycles, heating up to 1200ºC (without soaking time), cooling up to 400ºC, 171 cycles in the Accelerated ageing test bench (AATB) [Cañadas et al.] in a solar furnace
⇒ Solar cycling: heating up to 1200ºC (soaking time: 10 min), cooling up to 400ºC, 15 cycles in the AATB in a solar furnace

3. RESULTS

The following tables and figures summarize the results obtained.

In table 1 unfired properties of compacts are shown, seeing that bulk density increases when the proportion of black pigment is increased as a result of the higher true density of the pigment in comparison with alumina.

Table 1. Unfired properties of samples prepared with black pigments, compared with alumina.

Pigment	CT3000SG	5BL2	10BL2	15BL2	30 BL2
Pigment proportion (wt%)	0	5	10	15	30
Unfired bulk density (g/cm^3)	2.24	2.31	2.38	2.41	2.60

Figure 1 shows sintering diagram of compositions with several pigment content, compared with alumina. The higher the pigment content, the higher the bulk density at different temperatures.

Figure 2 depicts the variation of L*-coordinate (representative of luminosity) of the compacts with sintering temperature, compared with alumina. L*-coordinate decreased when black pigment content was increased.

Table 2 indicates the fired properties of compacts, at maximum densification temperature, compared with properties of silicon carbide Densitek15 (pressed and sintered by Fiven Norge). The addition of pigment reduced the sintering temperature of alumina, obtaining samples with open porosity near zero. Emissivity was not affected by the pigment addition while absorbance and conductivity depended on the pigment content. Some data of 30BL2 were not tested, since this composition showed cracks after the electrical aging test.

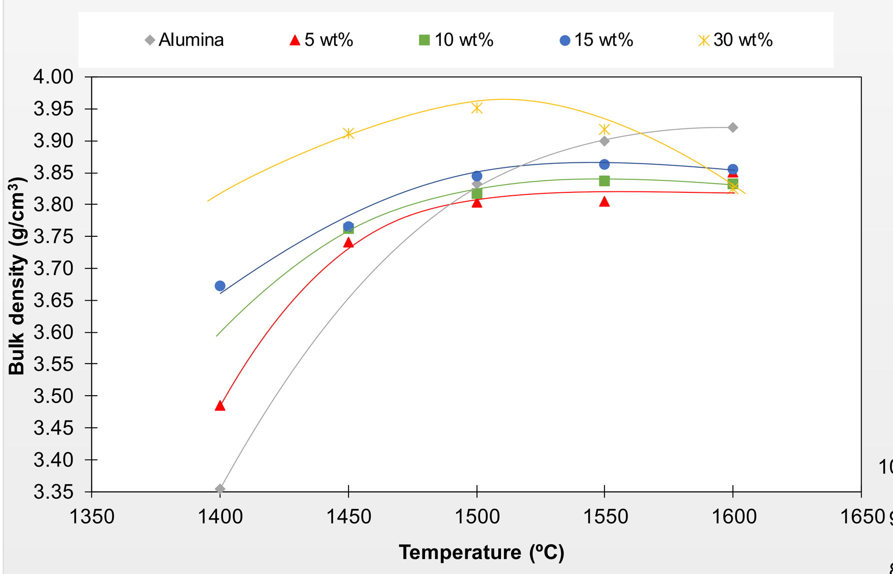


Figure 1. Sintering diagram of compositions with several black pigment content, compared with alumina CT300SG (0 wt% black pigment).

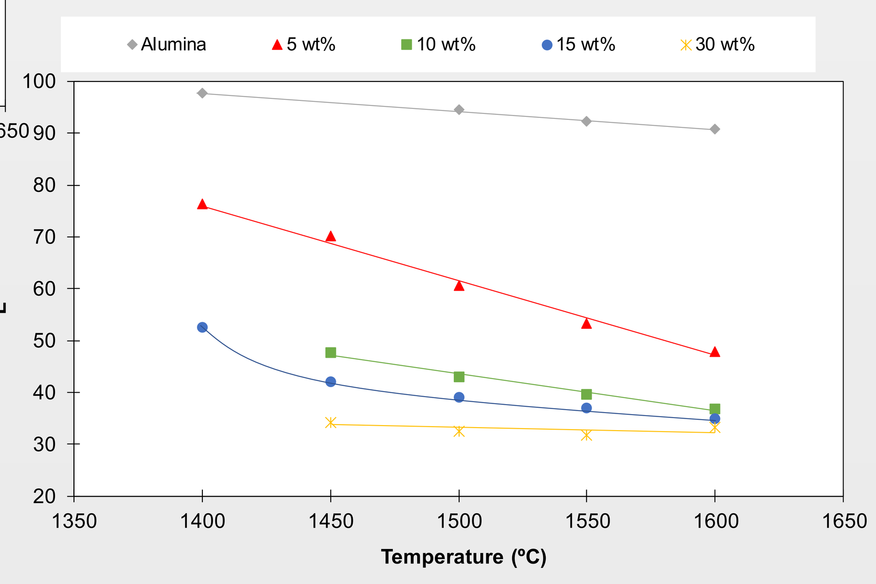


Figure 2. Variation of chromatic coordinate L* with temperature of compacts with several black pigment content, compared with alumina CT3000SG (0 wt% pigment).

Table 2. Fired properties at maximum densification temperature (Tmax) of compacts prepared with black pigments, compared with alumina and silicon carbide.

Pigment	Densitek15	CT3000SG	5BL2	10BL2	15BL2	30 BL2
Pigment content (wt%)	0	0	5	10	15	30
Tmax (ºC)	2110*	1600	1600	1550	1550	1500
Bulk density (g/cm^3)	3.17	3.91	3.85	3.84	3.86	3.95
Open porosity (%)	0.0	0.7	0.0	0.0	0.1	0.2
Emissivity	0.90*	0.64	0.69	0.68	0.68	-
Absorbance	0.85*	0.21	0.78	0.86	0.87	-
Conductivity (W/mK)	175*	32.4	14.2	12.7	11.8	-

** Values from different sources: Fiven catalogues, www.goodfellow.com; www.engineeringtoolbox.com; L. Charpentier et al.*

Figure 3 depicts the colour difference (obtained from chromatic coordinates) after all the different thermal treatments, compared with alumina and silicon carbide samples. Composition with 30 wt% black pigment has not been drawn, since all compacts broke after the electrical cycling test. Colour difference is related with the degradation of the compacts and, consequently, with the electrical and optical properties (emissivity, absorbance and conductivity). Bulk density and open porosity remained unchanged after all the thermal treatments applied.

Figure 4 shows the appearance of all compacts before and after the solar thermal treatments (cycling and accelerated). It is remarkable the small visual changes in the compacts with black pigments. Figure 5 shows the solar oven Sf40 during tests (located at Plataforma Solar de Almería).

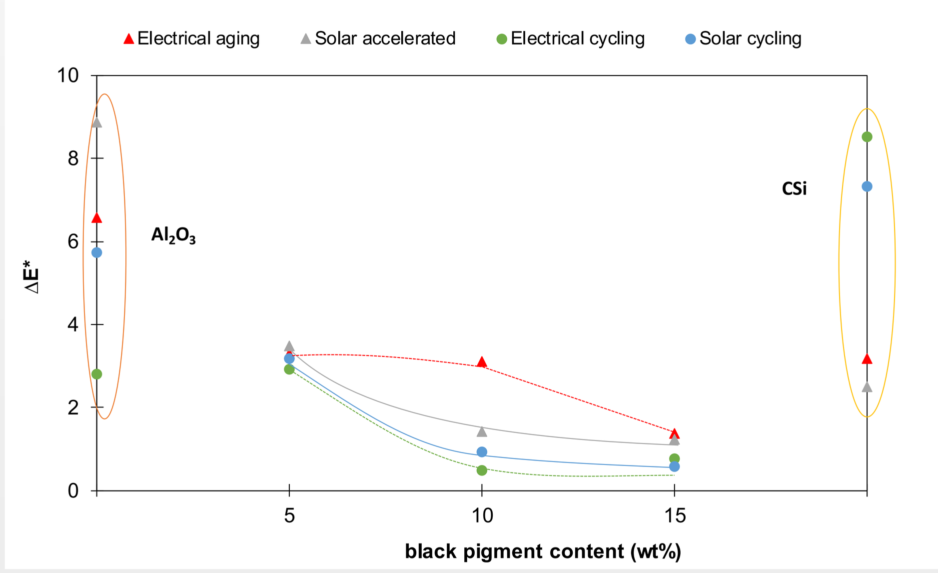


Figure 3. Colour difference (ΔE*) of compacts with several black pigment contents after the thermal treatments.

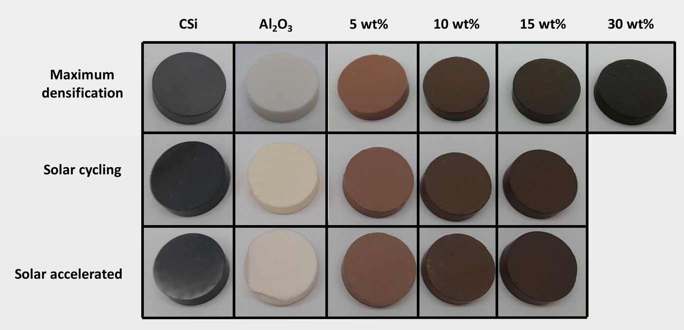


Figure 4. Aspect of the compacts pre and post testing.

Figure 5. Solar oven SF40 (located at Plataforma Solar de Almería) conducting the solar cycling tests.

4. CONCLUSIONS

⇒ Unfired bulk density of compacts showed higher values than those of alumina, partially because black pigment presents higher true density (4.6 g/cm^3 vs 4.0-4.1 g/cm^3 of alumina).
⇒ The addition of black pigment reduced the fired bulk density and the temperature necessary to reach open porosity below 0.5%.
⇒ L*-coordinate, which represents luminosity, decreases drastically when black pigment was added to alumina. The higher the pigment content or the sintering temperature, the lower the L*-coordinate.
⇒ Emissivity remains practically constant when black pigment was added in different proportions to alumina (0.64-0.69), being lower than those of silicon carbide (0.83-0.96).
⇒ Absorbance increases abruptly in compacts when black pigment was added to alumina, reaching similar values to those of silicon carbide (≈0.85). The higher the pigment content, the higher the absorbance.
⇒ After electrical cycling aging, only the compacts with 30wt% pigments were broken owed to the low thermal shock resistance. This composition was dismissed for the rest of aging tests.
⇒ Fired bulk density and open porosity remained constant after all types of aging tests conducted.
⇒ Compacts with black pigment showed a slightly change in colour after the aging tests, being the electrical aging the one with higher impact in the colour difference. Respect to cycling tests, solar had higher impact than electrical.
⇒ Colour difference was lower when the black pigment content increased. Values were lower than those of alumina (0 wt% black pigment) and silicon carbide.
⇒ Future work: other properties and microstructure of tested compacts will be analysed.

5. REFERENCES

[1] T. A. Otitoju et al. Advanced ceramic components: Materials, fabrication, and applications https://doi.org/10.1016/j.jiec.2020.02.002
[2] 2. High temperature accelerated ageing of advanced ceramic specimens for solar receivers and other applications under concentrated solar radiation https://www.cencenelec.eu/media/CEN-CENELEC/CWAs/RI/cwa17726_2021.pdf
[3] L. Charpentier et al. Influence of the porosity of SiC on its optical properties and oxidation kinetics. AIP Conference Proceedings 2126-1 (2019), 030013.
[4] Cañadas, I. et al. Characterization of Solar-Aged Porous Silicon Carbide for Concentrated Solar Power Receivers. Materials 2021, 14, 4627. https://doi.org/10.3390/ma14164627

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.