Chemical and physical characterization of fragments from ceramic jars called "formas de açúcar" exhumed in the town of Machico, Madeira island

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ABSTRACT The present paper deals with the chemical and physical characterisation of fragments from the ceramic jars called "formas de açúcar" exhumed at several archaeological sites in the town of Machico, Madeira Island.
Both minerals and high temperature crystalline phases were determined by X-Ray Diffraction (XRD) analysis, and the chemical composition was determined by X-Ray Fluorescence (XRF) analysis. This type of ceramics hardly could be manufactured in Madeira, a volcanic island, characterised by the scarce occurrence of clay deposits. However, the available analytical data indicates that the region of Aveiro, in Portugal continental, could be the source and the production centre of "formas de açúcar", which would be exported to Madeira through the important co mmercial harbour of Aveiro.
As a matter of fact, similarities were found between the studied ceramic fragments and the heavy clays which occur in huge deposits in the Aveiro region. Also, it was possible to estimate the maximum firing temperature (≈800°C) at which "formas de açúcar" have been fired.

Introduction

Particularly during the 15th and 16th centuries the Madeira island played an important role in the cultivation of sugar cane, as well as in the production and co mmercialisation of sugar. This called "white gold", being exported, did represent during long period of time a fundamental complement to the economic, social and cultural vitality of the island, promoting the welfare and the acquisition of important goods, still visible in the territory, independently of the cultivation of cereals and later on of wine.

Not so remarkable than in other places of the island, due most probably to climatic and orographic conditions not so favourable, sugar cane cultivation in the Capitania de Machico, had, at least initially, a paramount contribution to the structured settlement and economic development.

According to the chronicler Gaspar Frutuoso, the first production tests of sugar have taken place in Machico: *"primeiro asucre que se vendeo nesta Ilha da Madeira foi na Villa de Machiquo donde se começou há fazer e recolherão treze arrobas delle que se vendeo cada arroba por cinquo cruzados (...)*[4]".

The so-called "formas de açúcar" were conic ceramic jars having a hole at the bottom, being used to purge the sugar cake. This type of cake named "pão de açúcar" was exported from Madeira Island to Continenal Portugal and to other european countries. "Formas de açúcar" were imported, due to the poor quality of the clay raw materials available in Madeira[5], considered to be required for their manufacture.

Essentially, the present paper deals with the chemical and physical characterisation of some fragments of "formas de açúcar" exhumed in three archaeological sites of the town of Machico (Fig. 1): "Solar do Ribeirinho" (Sousa, 2000), "Junta de Freguesia" and "Alfândega". From these studies would be expected relevant information, able to identify both sources and production centers of these ceramic jars in mainland Portugal.

Materials and methods

The archaeological works being carried out in the urban area of the actual town of Machico allowed the identification of both structures and objects (ceramic fragments of "formas de açúcar"), of particular interest for a historical as well as social and economic study of the town. Fragments of "formas de açúcar" occur widespread in the archaeological strata dated of the 15th, 16th and 17th centuries (Sousa, 2003), pointing out that, besides the use for sugar processing, they could have been used for domestic purposes.

The present study intends to disclose, in a synthetic manner, the results of both chemical and typological analyses corresponding to eleven fragments of "formas de açúcar" found in well individualized stratigraphic layers at the archaeological sites, whose chronological limits are the 16th and 17th centuries.

Big and small "formas de açúcar", with distinct capacities were found. The smaller ones show, as a rule, a rounded edge without external pattern, whereas the bigger ones show an edge outwardly projected. However, most of the studied fragments correspond to intermediate sizes having diameters within the range 220-310 mm.[7]

Mineralogical and chemical analyses of the ceramic fragments from "formas de açúcar" were carried out using the analytical techniques, X-Ray Diffraction (XRD) and X-Ray Fluorescence (XRF). Indeed, these techniques have been decisive for the identification, with reasonable certainty, of the production centres of "formas de açúcar" in the Continent of Portugal.

Results

Tables I, II and III contain, under the form of acronyms, the field references (for ex., S. RIB/98 - 4.47) and the laboratory references (for ex., AM1) given to the studied ceramic fragments, as well as the following physical characteristics: Edge Thickness (EB); Wall Thickness (EP); Maximum Thickness (EM); External Surface (SE) and Internal Surface (SI).

TABLE I

Ceramic fragments from "formas de açúcar" exhumed at the Solar do Ribeirinho archaeological site, Machico town.

Acronym	Archeological site	U.E.	Description
S. RIB/98 - 4-47 (AM2)	Solar do Ribeirinho	Ditch 4	Edge and wall fragment of "forma de açúcar" Edge thickness: 14 mm SE: orange colour (M 45, CAILLEUX).
S. RIB/98 -4-100 (AM6)	Solar do Ribeirinho	4	Fragment of "forma de açúcar" EB: 14 mm Wall thickness: 11 mm SE: red colour, M39 SI: brown reddish colour, M35

TABLE I [cont.]

Acronym	Archeological site	U.E.	Description
S. RIB/98 - 3-101 (AM4)	Solar do Ribeirinho		Fragment of "forma de açúcar" Small diameter Non plastic elements of great dimensions Paste exhibiting rose colour EB: 15 mm EP: 10 mm SE: M40
S. RIB/98 - 3-102 (AM8)	Solar do Ribeirinho	3	Fragment of "forma de açúcar" EB: 16 mm SE: red colour, M39
S. RIB/98 - 3-103 (AM7)	Solar do Ribeirinho	3	Fragment of " forma de açúcar" EB: 13 mm SE: light red colour, N39

U.E. - stratigraphic unit

TABLE II

Ceramic fragments from "formas de açúcar" exhumed at Junta de Freguesia de Machico archaeological site, Machico town.

Acronym	Archeological site	U.E.	Description
JFM/00 - Vala3 - 304 (AM5)	Junta de Freguesia Vala (ditch) 3	Ditch 3	Edge and wall fragment of "forma de açúcar" EB: 9 mm Wall thickness: 11 mm SE: light red colour, N37 SI: red colour, P13
JFM/00-Vala1-3-300 (AM10)	Junta de Freguesia de Machico Vala (ditch) 1	3	Wall fragment of a " forma de açúcar" EP: dark brown colour P13 SI: light brownish-reddish colour, N37
JFM/00- Vala1-3-301 (AM11)	Junta de Freguesia de Machico Vala (ditch) 1	3	Wall fragment of a "forma de açúcar" EP: 9 mm SE: light brownish-reddish colour N30
JFM/00 - 3- 302 (AM9)	Junta de Freguesia de Machico	3	Wall fragment of a "forma de açúcar" Maximum thickness: 13 mm SE: cor castanho avermelhado claro, N37
JFM - 4- 150 (AM12)	Junta de Freguesia de Machico	4	Ceramic fragment (pobably construction ceramic) EP: 17 mm SE: brown reddish colour, R53

TABLE III

Ceramic fragment from one "forma de açúcar" exhumed at the old Alfândega de Machico archaeological site, Machico town.

Acronym	Archeological site	U.E.	Description
ALF/OO - 7-30 (AM3)	Alfândega de Machico	Ditch 7	Edge and wall fragment belonging to a "forma de açúcar" of great dimensions EB: 21 mm EP: 9 mm SE: light red colour, N37 SI: brown reddish colour, N35

TABLE IV

Chemical data (major elements, in %) of ceramic fragments from "formas de açúcar" exhumed at the three studied archaeological sites of Machico town.

Samples	Fe_2O_3	MnO	TiO_2	CaO	K_2O	P_2O_5	SiO_2	Al_2O_3	MgO	Na_2O	SO_3	P.R.
AM1	4,97	0,03	0,78	0,29	4,54	0,11	67,80	18,18	1,61	0,44	0,12	0,96
AM2	5,87	0,02	0,77	0,16	3,85	0,07	67,51	18,43	1,36	0,38	0,11	0,94
AM3	4,27	0,03	0,84	0,14	4,25	0,08	70,82	16,40	1,35	0,59	0,11	0,75
AM4	6,04	0,04	0,97	0,20	3,96	0,16	66,48	18,66	1,38	0,45	0,13	1,50
AM5	7,72	0,02	0,60	0,31	2,08	0,18	67,99	19,08	0,59	0,23	0,13	0,86
AM6	6,18	0,04	1,06	0,18	3,74	0,11	66,07	19,46	1,51	0,52	0,13	1,03
AM7	5,58	0,03	0,77	0,18	4,13	0,26	64,58	20,12	1,71	0,50	0,33	1,09
AM8	6,12	0,09	0,79	0,73	3,47	0,10	67,10	18,13	1,40	1,05	0,13	0,90
AM9	10,37	0,06	0,71	0,95	2,33	0,59	62,47	18,64	0,87	0,52	0,18	2,12
AM10	4,73	0,03	0,07	0,32	4,44	0,09	67,16	19,40	1,54	0,31	0,13	1,10
AM11	5,84	0,03	0,87	0,26	3,54	0,11	66,61	19,73	1,48	0,30	0,17	0,65
Aveiro clay	7,40	0,04	0,62	0,64	4,53	0,12	63,90	20,05	1,90	0,30	0,12	0,70

TABLE V

Chemical data (minor and trace elements, in ppm) of ceramic fragments from "formas de açúcar" exhumed at the three studied archaeological sites of Machico town.

Samples	Ba	Sn	Nb	Zr	Y	Sr	Rb	Pb	As	Zn	W	Cu	Ni	Co	Cr	V
AM1	374	27	25	256	34	132	258	39	39	83	18	19	26	<5	66	53
AM2	303	23	23	198	32	100	236	38	37	61	7	16	24	<5	63	55
AM3	375	32	24	368	35	132	238	45	17	66	8	17	27	<5	57	53
AM4	302	18	25	401	32	100	208	33	11	56	<5	14	28	<5	74	61
AM5	587	<5	15	187	31	114	131	40	24	49	<5	18	55	<5	146	65
AM6	333	144	30	239	32	110	218	44	22	83	<5	16	28	<5	117	64
AM7	291	18	23	216	31	102	223	29	19	48	<5	14	28	<5	72	65
AM8	493	8	18	204	29	109	172	82	35	107	<5	25	46	<5	93	72
AM9	476	<5	11	179	27	404	126	49	67	173	<5	25	60	<5	168	88
AM10	349	17	26	243	36	130	271	43	28	58	<5	42	32	<5	59	53
AM11	474	34	26	243	31	121	225	42	18	65	<5	19	35	<5	77	65
Aveiro clay	454	23	25	280	32	146	231	44	31	76	<5	19	43	<5	80	70

TABLE VI

Mineral composition of ceramic fragments of "formas de açúcar" exhumed at the three studied archaeological sites of the Machico town.

Samples	Quartz	K-feldspar	Na-Ca feldspar	Mica/Illite	Hematite	Dolomite and calcite
AM1	33%	7%	%	50%	5%	5%
AM2	38	7		43	6	6
AM3	38	5		45	4	8
AM4	37	9		40	7	7
AM5	55	5		25	8	7
AM6	33	8	8	40	6	5
AM7	37	5		47	6	5
AM8	39	5		44	6	6
AM9	45	5		30	10	10
AM10	36	10		45	5	4
AM11	27	5	20	37	6	5

Tables IV and V show the results of the chemical analyses for major and trace elements, respectively, determined by XRF, on the studied eleven ceramic fragments from "formas de açúcar".

Table VI shows both minerals and crystalline high temperature phases identified in the ceramic fragments, determined by XRD.

Chemical and mineralogical results (Tables, IV, V and VI) allow to consider that "formas de açúcar" could have been manufactured in the Aveiro region, an important production centre of pottery and structural ceramics, as well as an important co mmercial harbour at that time and in the present day.

Nowadays, particularly close to the channels of the so-called Ria de Aveiro, fragments of "formas de açúcar" are relatively easy to find, either incorporated in soils and sediments, or incorporated into old house walls.

In the Aveiro region there are huge deposits of heavy clays that belong to the geological formation "Argilas de Aveiro", dated of the Upper Cretaceous. They are illite rich clays in which illite is associated with other clay minerals, irregular mixed-layers of illite-smectite, smectite and kaolinite. Dolomite, quartz and calcite are the main non clay minerals participating in the composition of these clays. When fired, they show red colour, in darker or lighter shades, depending upon the iron content, usually high, that could be as goethite and/or hematite.

It is well known that high iron contents favour the vitrification of the ceramic bodies at lower temperatures, which able the ceramic bodies to acquire good values of mechanical resistance at lower firing temperatures.

The chemical composition of most of the fragments of "formas de açúcar", exhumed in Machico, is close to the chemical composition of the clays from Aveiro (see Tables IV and V).

The Aveiro clay that was used for comparative purposes was collected in the quarry of Vilar, nowadays in the urban area of Aveiro, and disactivated. The Aveiro clay, before being chemically analysed, was fired up to 800°C with a residence time at the maximum temperature estimated at 30 min.

Most of the hydrated phyllosilicates of the ceramic samples belong to the mica group, being frequently macroscopically identified, and still persisting in the XRD patterns. This fact indicates that their crystalline structures were not fully collapsed by firing, pointing to maximum firing temperatures in kilns feeded with wood. Despite being low, the values of I.L. (ignition loss) indicate that some hydroxylic or structural water still remains. Also, the XRD patterns show the presence of an amorphous or glassy component.

On the other hand, the persistence in some ceramic fragments of dolomite, $CaMg(CO_3)_2$, identified by XRD (particularly in samples Am3, Am4, Am5 and Am9), indicates that the maximum firing temperature (≈800°C) was not sufficient to achieve the total decomposition of this mineral that currently occurs in the geological formation "Argilas de Aveiro". Dolomite is either absent or very unco mmon in heavy clays of any other Portuguese clay deposits.

NOTES

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[4] Cfr. Gaspar Frutuoso, *Livro Segundo das Saudades da Terra*, Ponta Delgada, 1968, p., 146.

[5] In a brief look into the Livros de Vereações da Câmara Municipal do Funchal dated of XVI and XVII centuries numerous references were found about pottery works and the imposition of the municipality with regards the production of pottery.

[6] Excavations carried out by Cláudio Torres at the site named Mata da Machada, Barreiro, did show two models of "formas de açúcar" that could be transported to the portuguese atlantic archipelagos (Torres, sd.).

[7] In the study referred to and concerned with the archaeological works carried out in the urban área of Machico a typological classification was proposed based upon three models of "formas de açúcar" exhibiting remarkable typological and metrical differences (Sousa, 2003:181-183).

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