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REUSE OF GLASS FIBER WASTE IN THE CIRCULAR ECONOMY

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ABSTRACT: Due to the high B_2O_3 content of E-type fibres, as well as the beneficial qualities of basaltic fibres, make this waste an effective alternative use in frits and glazes without PbO (considered toxic). We proposed 7 frit recipes (made with basalt fibre waste and E-type fibre) and 1 glaze recipe with E-type and B-type frit (from basalt fibre waste) whose compositions were established based on an additive calculation program. The wetting capacity and the thermal expansion of these frits and glazes were studied. The mathematical modelling - based on the experimental data - of the complex dependencies between the content of E-glass fibres, respectively, of basaltic fibres and their wetting capacity and thermal expansion properties were performed.

KEYWORDS: glass fibre waste, circular economy

1. INTRODUCTION

The research approaches a present subject, namely the one regarding the recovery of some industrial waste to obtain useful products - a major priority in terms of environmental protection, sustainable development and economics, as well, using the advantages offered by the oxide composition and the energy incorporated in the glass waste [1-4].

In the same context, the potential for reuse of waste is the essential criterion in equating the notion of waste with that of secondary raw material, as E-glass fibre waste (about 2400 tonnes / year) and basaltic fibres (approx. 100 t / year) can be considered [5-7]. Being non-degradable they are polluting, but they represent a valuable potential for recoverable raw materials, as well as the large amount of energy incorporated in the glass which could lead to substantial fuel savings.

Considering the relatively large volume of waste resulting from the manufacturing processes of the two types of glass oxide fibres on the one hand, as well as the benefits that their use would have, on the other hand, the attempt to fully capitalize them in the most efficient way by making valuable products such as glazes is justified.

2. EXPERIMENTAL

The vitreous oxide fibre waste resulting from the manufacturing process of E-glass (a special type of glass used in electronics) fibres and of the basaltic fibres resulting from the manufacturing process of mineral wool (a thermal insulating product), can be an efficient alternative of valorisation in frites and glazes for construction materials, such as: terracotta tiles, sanitaryware, stoneware and even for household and decorative tile products [5-7].

The advantages of their use are given by the addition in the glaze recipes of some valuable components (B_2O_3, CaO, Al_2O_3), by saving of raw materials and energy, and by greening the environment. The high B_2O_3 content of E-type fibres, as well as the beneficial qualities of basaltic fibres, may recommend their use in frites and glazes without PbO (considered toxic) [8-11].

We proposed 5 frit recipes (tables 1-5) made with fibre waste, whose compositions were established based on an additive calculation program.

A glaze recipe was also made with E-type frit (obtained from E-fibre waste) and B-type frit (obtained from basaltic fibre waste) (table 6).

Table 1. Frit composition from basalt fibre waste - recipe (II 1B)

Raw material	% wt	g	P.C.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	B_2O_3	TiO_2	Total
Basalt fibre waste	composition %		0.00	50.42	15.29	8.82	9.26	11.85	1.80	1.10	0.00	1.41	99.95
	weighted to 100 %		0.00	50.45	15.30	8.82	9.26	11.86	1.80	1.10	0.00	1.41	100.00
	80.00	80.00	0.00	40.34	12.23	7.06	7.41	9.48	1.44	0.88	0.00	1.13	79.96
Technic borax	composition %		48.21	0.00	0.00	0.00	0.00	0.00	14.54	0.00	37.25	0.10	100.10
	weighted to 100 %		48.16	0.00	0.00	0.00	0.00	0.00	14.53	0.00	37.21	0.10	100.00
	20.00	38.58	18.58	0.00	0.00	0.00	0.00	0.00	5.60	0.00	14.36	0.04	20.00
Total	100.00	118.58	18.58	40.34	12.23	7.06	7.41	9.48	7.04	0.88	14.36	1.17	99.96

Oxide composition % wt.	**40.35**	**12.24**	**7.06**	**7.41**	**9.48**	**7.05**	**0.88**	**14.36**	**1.17**	**100.00**
Oxide composition moles	0.67	0.12	0.04	0.13	0.24	0.11	0.01	0.21	0.01	1.55
Oxide composition (molar fraction)	**0.43**	**0.08**	**0.03**	**0.09**	**0.15**	**0.07**	**0.01**	**0.13**	**0.01**	
Seger formula	1.37	0.24	0.09	0.27	0.48	0.23	0.02	0.42	0.03	
Coefficient of thermal expansion * 10^{-7}	38.00	-30.00	110.00	130.00	60.00	395.00	465.00	-8.25	39.87	**68.68**

Table 2. Frit composition from basalt fibre waste - recipe (II 5B)

Raw material	% wt	g	P.C.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	B_2O_3	TiO_2	Total
Feldspat	composition %		0,90	75,40	14,10	0,76	0,98	0,14	4,30	3,30	0,00	0,04	99,92
	weighted to 100 %		0,90	75,46	14,11	0,76	0,98	0,14	4,30	3,30	0,00	0,04	100,00
	10,00	10,09	0,09	7,61	1,42	0,08	0,10	0,01	0,43	0,33	0,00	0,00	10,00
Technic borax	composition %		48,21						14,54		37,25	0,10	100,10
	weighted to 100 %		48,16	0,00	0,00	0,00	0,00	0,00	14,53	0,00	37,21	0,10	100,00
	30,00	44,45	14,45	0,00	0,00	0,00	0,00	0,00	6,46	0,00	16,54	0,04	23,04
Basalt fibre waste	composition %		0,00	50,42	15,29	8,82	9,26	11,85	1,80	1,10	0,00	1,41	99,95
	weighted to 100 %		0,00	50,45	15,30	8,82	9,26	11,86	1,80	1,10	0,00	1,41	100,00
	60,00	60,00	0,00	30,27	9,18	5,29	5,56	7,11	1,08	0,66	0,00	0,85	60,00
Total	100,00	114,54	14,54	37,88	10,60	5,37	5,66	7,13	7,97	0,99	16,54	0,89	93,04
Oxide composition % wt.				**40,71**	**11,40**	**5,77**	**6,08**	**7,66**	**8,57**	**1,07**	**17,78**	**0,96**	**100,00**
Oxide composition moles				0,68	0,11	0,04	0,11	0,19	0,14	0,01	0,25	0,01	1,54
Oxide composition (molar fraction)				**0,44**	**0,07**	**0,02**	**0,07**	**0,12**	**0,09**	**0,01**	**0,16**	**0,01**	
Seger formula				1,51	0,25	0,08	0,24	0,43	0,31	0,03	0,56	0,03	
Coefficient of thermal expansion * 10^{-7}				38,00	-30,00	110,00	130,00	60,00	395,00	465,00	-7,21	38,99	**71,67**

Table 3. Frit composition from basalt and E-fibre wastes - recipe (II 4B)

Raw material	% wt	g	P.C.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	B_2O_3	TiO_2	Total
Basalt fibre waste	composition %		0,00	50,42	15,29	8,82	9,26	11,85	1,80	1,10	0,00	1,41	99,95
	weighted to 100 %		0,00	50,45	15,30	8,82	9,26	11,86	1,80	1,10	0,00	1,41	100,00
	50,50	50,50	0,00	25,46	7,72	4,45	4,68	5,98	0,91	0,56	0,00	0,71	50,47
Technic borax	composition %		48,21						14,54		37,25	0,10	100,10
	weighted to 100 %		48,16	0,00	0,00	0,00	0,00	0,00	14,53	0,00	37,21	0,10	100,00
	11,50	22,18	10,68	0,00	0,00	0,00	0,00	0,00	3,22	0,00	8,26	0,02	11,50
E-fibre wastes	composition %		0,00	53,21	14,73	0,16	18,52	3,21	0,77	0,12	9,27	0,00	99,99
	weighted to 100 %		0,00	53,21	14,73	0,16	18,52	3,21	0,77	0,12	9,27	0,00	100,00
	38,00	38,00	0,00	20,22	5,60	0,06	7,04	1,22	0,29	0,05	3,52	0,00	38,00
Total	100,00	110,68	10,68	45,68	13,32	4,52	11,71	7,20	4,42	0,60	11,78	0,73	99,97
Oxide composition % wt.				**45,70**	**13,32**	**4,52**	**11,72**	**7,21**	**4,43**	**0,60**	**11,78**	**0,73**	**100,00**
Oxide composition moles				0,76	0,13	0,03	0,21	0,18	0,07	0,01	0,17	0,01	1,57
Oxide composition (molar fraction)				**0,49**	**0,08**	**0,02**	**0,13**	**0,12**	**0,05**	**0,00**	**0,11**	**0,01**	
Seger formula				1,63	0,28	0,06	0,45	0,39	0,15	0,01	0,36	0,02	
Coefficient of thermal expansion * 10^{-7}				38,00	-30,00	110,00	130,00	60,00	395,00	465,00	-11,62	32,01	**61,11**

Table 4. Frit composition from E-fibre waste - recipe (II 1E)

Raw material	% wt	g	P.C.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	B_2O_3	TiO_2	Total
Technic borax	composition %		48,21	0,00	0,00	0,00	0,00	0,00	14,54	0,00	37,25	0,10	100,10
	weighted to 100 %		48,16	0,00	0,00	0,00	0,00	0,00	14,53	0,00	37,21	0,10	100,00
	20,00	38,58	18,58	0,00	0,00	0,00	0,00	0,00	5,60	0,00	14,36	0,04	20,00

E-fibre wastes	composition %		0,00	53,21	14,73	0,16	18,52	3,21	0,77	0,12	9,27	0,00	99,99
	weighted to 100 %		0,00	53,21	14,73	0,16	18,52	3,21	0,77	0,12	9,27	0,00	100,00
	80,00	80,00	0,00	42,57	11,79	0,13	14,82	2,57	0,62	0,10	7,42	0,00	80,00
Total	100,00	118,58	18,58	42,57	11,79	0,13	14,82	2,57	6,22	0,10	21,77	0,04	100,00
Oxide composition % wt.				**42,57**	**11,79**	**0,13**	**14,82**	**2,57**	**6,22**	**0,10**	**21,77**	**0,04**	**100,00**
Oxide composition moles				0,71	0,12	0,00	0,26	0,06	0,10	0,00	0,31	0,00	1,57
Oxide composition (molar fraction)				**0,45**	**0,07**	**0,00**	**0,17**	**0,04**	**0,06**	**0,00**	**0,20**	**0,00**	
Seger formula				1,65	0,27	0,00	0,62	0,15	0,23	0,00	0,72	0,00	
Coefficient of thermal expansion * 10^{-7}				38,00	-30,00	110,00	130,00	60,00	395,00	465,00	-10,06	37,11	**63,04**

Table 5. Frit composition from E-fibre waste - recipe (II 5E)

Raw material	% wt	g	P.C.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	B_2O_3	TiO_2	Total
Feldspat	composition %		0,90	75,40	14,10	0,76	0,98	0,14	4,30	3,30	0,00	0,04	99,92
	weighted to 100 %		0,90	75,46	14,11	0,76	0,98	0,14	4,30	3,30	0,00	0,04	100,00
	10,00	10,09	0,09	7,61	1,42	0,08	0,10	0,01	0,43	0,33	0,00	0,00	10,00
Technic borax	composition %		48,21						14,54		37,25	0,10	100,10
	weighted to 100 %		48,16	0,00	0,00	0,00	0,00	0,00	14,53	0,00	37,21	0,10	100,00
	30,00	44,45	14,45	0,00	0,00	0,00	0,00	0,00	6,46	0,00	16,54	0,04	23,04
E-fibre wastes	composition %		0,00	53,21	14,73	0,16	18,52	3,21	0,77	0,12	9,27	0,00	99,99
	weighted to 100 %		0,00	53,21	14,73	0,16	18,52	3,21	0,77	0,12	9,27	0,00	100,00
	60,00	60,00	0,00	31,93	8,84	0,10	11,11	1,93	0,46	0,07	5,56	0,00	60,00
Total	100,00	114,54	14,54	39,54	10,26	0,17	11,21	1,94	7,35	0,41	22,10	0,05	93,04
Oxide composition % wt.				**42,50**	**11,03**	**0,19**	**12,05**	**2,09**	**7,90**	**0,44**	**23,76**	**0,05**	**100,00**
Oxide composition moles				0,71	0,11	0,00	0,22	0,05	0,13	0,00	0,34	0,00	1,56
Oxide composition (molar fraction)				**0,45**	**0,07**	**0,00**	**0,14**	**0,03**	**0,08**	**0,00**	**0,22**	**0,00**	
Seger formula				1,77	0,27	0,00	0,54	0,13	0,32	0,01	0,85	0,00	
Coefficient of thermal expansion * 10^{-7}				38,00	-30,00	110,00	130,00	60,00	395,00	465,00	-8,81	36,76	**67,07**

Table 6. Glaze composition with frit from basalt and E-fibre wastes - recipe (I 2)

Raw material	% wt	g	P.C.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	B_2O_3	TiO_2	Total
Frit from basalt fibre waste	composition %		0,00	50,42	15,29	8,82	9,26	11,85	1,80	1,10	0,00	1,41	99,95
	weighted to 100 %		0,00	50,45	15,30	8,82	9,26	11,86	1,80	1,10	0,00	1,41	100,00
	37,00	37,00	0,00	18,66	5,66	3,27	3,43	4,39	0,67	0,41	0,00	0,52	37,00
Kaolin	composition %		12,75	47,10	37,33	0,98	0,23	0,18	0,20	0,99	0,00	0,10	99,86
	weighted to 100 %		12,77	47,17	37,38	0,98	0,23	0,18	0,20	0,99	0,00	0,10	100,00
	3,00	3,44	0,44	1,62	1,29	0,03	0,01	0,01	0,01	0,03	0,00	0,00	3,00
Frit from E-fibre waste	composition %		0,00	53,21	14,73	0,16	18,52	3,21	0,77	0,12	9,27	0,00	99,99
	weighted to 100 %		0,00	53,21	14,73	0,16	18,52	3,21	0,77	0,12	9,27	0,00	100,00
	60,00	60,00	0,00	31,93	8,84	0,10	11,11	1,93	0,46	0,07	5,56	0,00	60,00
Total	100,00	100,44	0,44	52,22	15,78	3,40	14,55	6,32	1,14	0,51	5,56	0,53	100,00
Oxide composition % wt.				**52,22**	**15,78**	**3,40**	**14,55**	**6,32**	**1,14**	**0,51**	**5,56**	**0,53**	**100,00**
Oxide composition moles				0,87	0,15	0,02	0,26	0,16	0,02	0,01	0,08	0,01	1,57
Oxide composition (molar fraction)				**0,55**	**0,10**	**0,01**	**0,17**	**0,10**	**0,01**	**0,00**	**0,05**	**0,00**	
Seger formula				1,97	0,35	0,05	0,59	0,36	0,04	0,01	0,18	0,01	
Coefficient of thermal expansion * 10^{-7}				38,00	-30,00	110,00	130,00	60,00	395,00	465,00	-20,26	22,06	**52,31**

3. RESULTS AND DISCUSSIONS

For these 6 compositions, preliminary tests were performed to evaluate the behaviour at high temperatures [12-21].

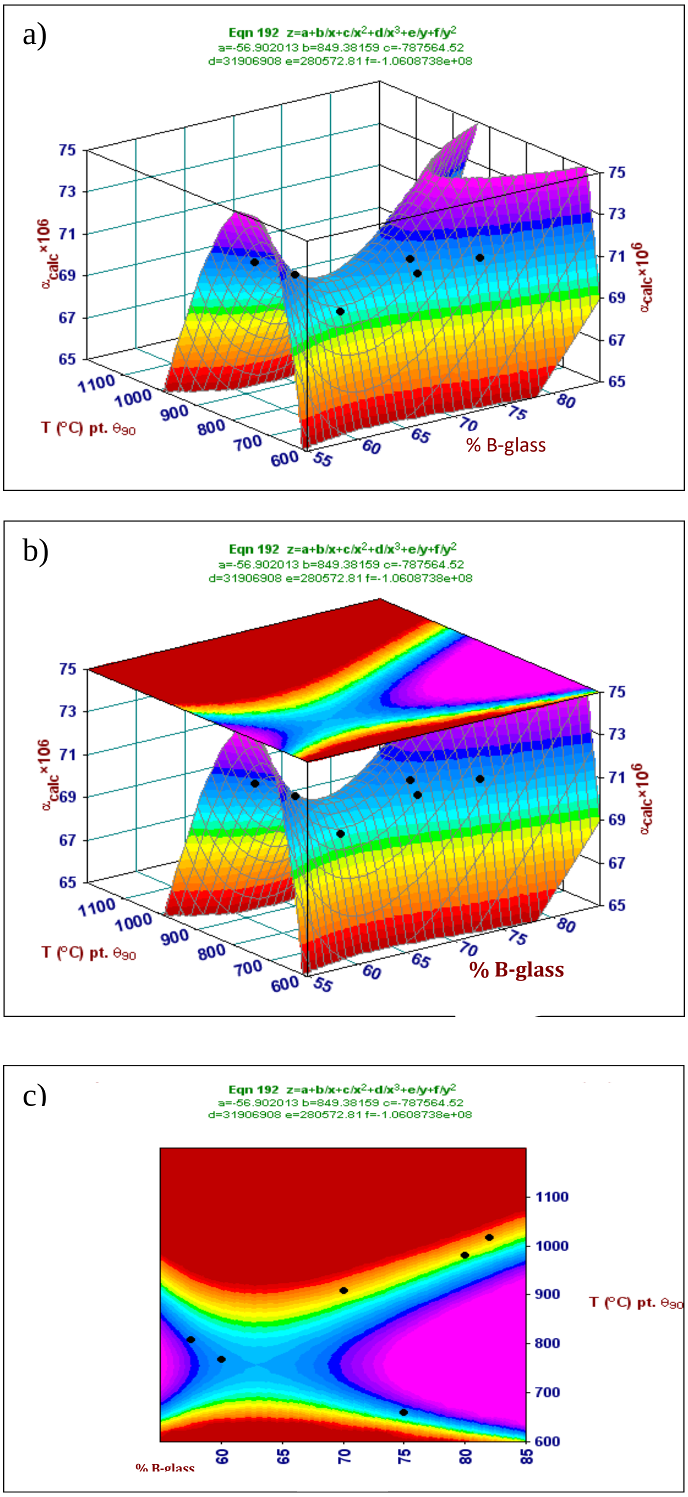

Figure 1. Coefficient of thermal expansion vs. % of B-glass and T (Θ_{90}) a- the projection of the 3D image; b- 2D plan of 3D image; c- the plane projections of the temperature corresponding to the wetting angle of Θ_{90} vs the composition of the glass

For this purpose we considered useful to study the wetting capacity, expressed by the variation of the wetting angle, θ, with the temperature and the thermal expansion and the synthetic presentation of the correlations between the E-glass fibre content and basaltic fibres, respectively, and the wetting and thermal expansion properties for of the obtained frits (Figs. 1-2).

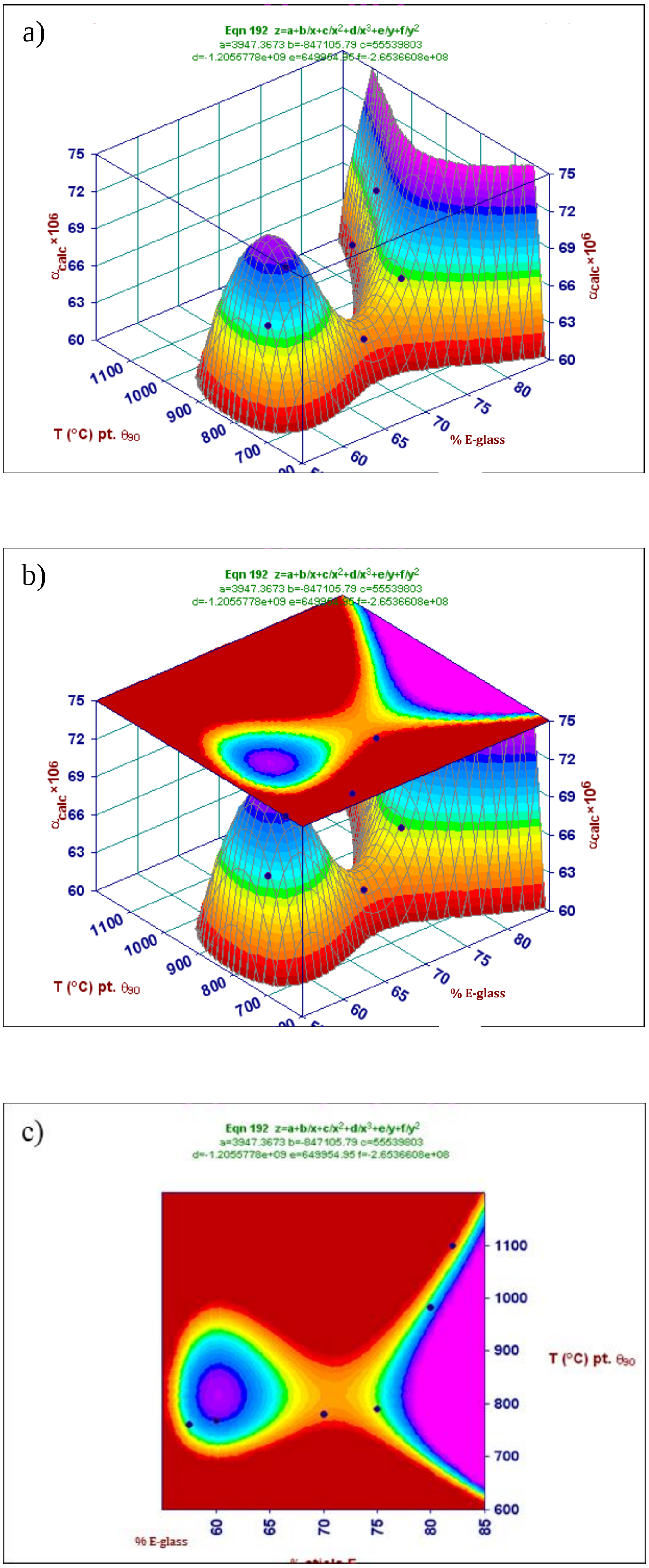

Figure 2. Coefficient of thermal expansion vs. % of E-glass and T (Θ_{90}) a- the projection of the 3D image; b- 2D plan of 3D image; c- the plane projections of the temperature corresponding to the wetting angle of Θ_{90} vs the composition of the glass

The mathematical modelling - based on the experimental data - of the existing complex dependencies has led to the deduction of some response surfaces, which illustrate the various compositional domains with optimal properties taking into account the temperature of 1100°C that terracotta can withstand (low thermal expansion coefficient and high wetting capacity at the lowest temperatures), as presented in Figures 1 and 2.

The 3D image corresponding to the relationship between the temperature T (Θ_{90}), the thermal expansion coefficient and the glass composition (abbreviated % of B-glass and, respectively, % of E-glass) is shown in Figures 1a and 2a. In the second image (b) of Figures 1 and 2, the projection of the 3D image, presented in (a), is made in plane (2D). In Figures 1c and 2c, only the projections in plane of the temperature corresponding to the wetting angle of Θ_{90} vs the composition of the glass is shown. The red and purple colours in Figures 1 and 2 represent the unwanted area, and the green colour represents the optimal area of the 3 parameters considered in the graphs.

Figures 1 (b, c) and 2 (b, c), respectively, allow, also, the visualization of the above-mentioned domains for the qualitative (b) and quantitative (c) evaluation of the compositional parameters necessary to obtain properties with imposed values (linear thermal expansion coefficient, wetting capacity, surface tension).

Thus, the following can be highlighted:

- all the studied samples possess satisfactory wetting capacity with respect to the terracotta substrate, being under 1100^{o}C;
- the wetting angle of the samples with basaltic fibre waste varies on smaller temperature ranges compared to those with E fibres, but all the samples are located near the optimum area (green area).

4. Conclusions

We proposed 5 frit recipes (made with basalt fibre waste and E-type fibre) and 1 glaze recipe with E-type and B-type frit (from basalt fibre waste) whose compositions were established based on an additive calculation program. The wetting capacity and the thermal expansion of these frits and glazes were studied.

The mathematical modelling - based on the experimental data - of the complex dependencies between the content of E-glass fibres, respectively, of basaltic fibres and their wetting capacity and thermal expansion properties were performed.

Following the analyses, it was found that:

- all the studied samples possess satisfactory wetting capacity with respect to the terracotta substrate;
- the wetting angle of the samples with basaltic fibre waste varies on smaller temperature ranges compared to those with E fibres, because the basaltic melt belongs to the category of "shorter" glasses (which can be processed quickly).

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