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Cullet recycling for the production of facing ceramics with self-glazing effect

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ABSTRACT

This paper presents the research results of application possibility of the most common types of cullet as a functional additive, which serves as a vitreous phase source for the production of facial ceramics based on low-plasticity clay. Boric acid is another charge additive, which contributes to the ceramics liquid-phase sintering, and together with cullet allows producing self-glazing effects of the products surface and glazing of the crystalline phase particles in the material depth. The research results reveal the influence of the cullet amount and its chemical composition on the principle performance properties of facing ceramics and confirm the application possibility of the developed charge composition for recycling cullet to produce high-quality ceramic products.

Key words: cullet, facing ceramics, self-glazing, low-plasticity clay, boric acid

1. INTRODUCTION

Cullet consists of the glass product fragments and pieces of glass formed in the course of the glass production and consumption. On the one hand, this type of waste is a valuable secondary resource and can be used unlimited times in production processes without any quality loss and by-products formation, thus saving primary resources. On the other hand, cullet is highly resistant to external impact (it does not decompose or burn, it is chemically resistant), so it can be accumulated in large quantities, which require landfills and storage sites. In this regard, cullet disposal is an important and urgent task[1-3].

Industrial cullet is almost completely processed by the industrial enterprises. Processing of the cullet formed in the process of industrial and domestic consumption is widespread and is actively developing abroad, while in Russia such technologies are not sufficiently developed and as a result, the share of cullet comprises up to 8-10 % of the total household waste. Additional difficulties for cullet processing in our country are associated with insufficiently effective system of waste selective collection and sorting. Therefore, the development of new cullet recycling methods is a promising area of research[4-6].

Like most industrial and consumption waste, the most promising area for cullet processing is the construction materials production, allowing disposal of various waste types both separately and comprehensively in large quantities.

The research authors have previously developed raw mixtures technologies and compositions allowing to produce ceramic and polymer composite products in the form of tiles for external and internal wall cladding of the buildings and structures using window glass cullet and unsorted container glass cullet[2, 7, 8]. The produced ceramic items had self-glazing effect of the surface and glazing in the products depth, providing production of material possessing high strength characteristics and frost resistance[7, 8].

The research objective was to study the application possibility of the most common types of cullet in the production of self-glazing facing ceramics meeting the regulatory requirements for face ceramic products.

2. RESEARCH OBJECTS AND METHODS

The main component of the charge for facing ceramics production was the clay from Suvorotskoye deposit in the Vladimir region of the following composition (wt. %): SiO_2= 67.5; Al_2O_3=10.75; Fe_2O_3= 5.85; CaO= 2.8; MgO= 1.7; K_2O= 2.4; Na_2O = 0.7. In compliance with GOST 9169-75 classification, this clay refers to the low-plasticity type, since plasticity determined according to the standard method is 5.2. Therefore, to produce high-quality products based on this clay, special additives are required [9, 10].

In this study B grade boric acid of 2nd class according to GOST 18704-78, containing at least 98.6 wt % of the basic substance was used as a fluxing and strengthening additive. Boric acid promotes liquid-phase sintering, providing the ceramics hardening and, alongside the additives which are vitreous phase source, obtaining self-glazing and vitrification effects[7, 9, 11].

The most common cullet types were used in this research as additives providing the vitreous phase formation. The average chemical composition of the cullet is shown in table 1. Waste products based on colorless (BT-1 grade), semi-white (PT-1 grade), green (ZT-1 grade) and brown (KT-1 grade) glass according to GOST R 52022-2003 were used as container glass cullet.

Table 1: Cullet chemical composition, wt. %

Glass	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Cr_2O_3
Window	73.5	0.9	-	7.4	1.9	11.1	5.2	-
Household	73.5	1.5	-	6.5	2	11.5	1.5	-
Container:								
BT-1	72.5	2.5	0.1	6.2	4,2	14.0	0.5	-
PT-1	72.1	2.8	0.5	6.2	4.2	14.2	-	-
ZT-1	71.4	2.7	0.8	6.2	4.2	14.5	-	0.2
KT-1	71.7	2.9	0.5	6.2	4.2	14.5	-	-

During the experiments, clay and cullet fractions were pre-crushed reaching the particle size of no more than 0.63 mm and dried up to constant mass. All the charge components were mixed dry in the specified ratios, then with 8 wt. % of water. The facing ceramics samples were formed from the resulting homogeneous mass at a specific pressing pressure of 15 MPa, with further firing at the maximum temperature of 1050 ^oC [7, 9, 11].

The compressive strength (σ_{cmp}, MPa) and bending strength (σ_{bnd}, MPa), water absorption (WA, %), frost resistance (FR, cycles), and density (ρ, kg/m^3) have been determined for the studied material samples in compliance with the standard methods for construction ceramics.

3. RESEARCH RESULTS AND DISCUSSION

Previously, to develop the charge based on the low-plasticity clay used in this work with the boric acid introduction and unsorted container glass cullet, the authors had found that the maximum strength and minimum water absorption are achieved at the introduction of 2.5 wt. % boric acid [7]. In this regard, similar amount of flux-strengthening additive was used in this paper with different amount of cullet types, selected for the research.

The experiments revealed that for the ceramics compressive strength, similar dependence character is observed on the amount of all cullet types used in the charge composition (Fig. 1). Herewith the introduction of less than 5 wt. % cullet slightly changes the strength of the resulting facing ceramics

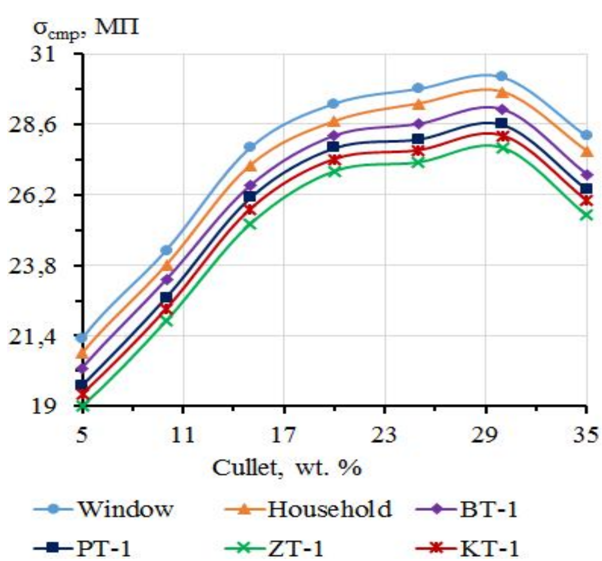

Figure 1. Strength dependence on cullet type and amount

The presented data demonstrates that the cullet introduction from 5 to 20 wt. % causes the most drastic strength increase of facing ceramics, depending on the pores and voids filling in the material with the vitreous phase formed during the joint introduction of boric acid and cullet. The introduction of cullet from 20 to 30 wt.% causes less intensive increase of ceramics strength, since at the given amount of the studied additive, most pores and voids in the material are already filled and the thickness of the vitreous phase layers between the ceramic particles increases. When over 30 wt. % of cullet is introduced the ceramics strength starts to decrease, as thickness of the vitreous phase layers increases so much that its brittleness and lower strength compared to the crystalline phases begins to affect the facing ceramics strength.

The strength difference between ceramic samples produced using different cullet types depends on the glass chemical composition. Cullet with the higher content of silicon, aluminum, calcium and magnesium oxides allows achieving higher ceramic strength, since these oxides increase the vitreous phase strength. Simultaneously sodium and potassium oxides amount in the cullet reduces the vitreous phase strength and the resulting ceramics as a whole. It is also worth noting that boron oxide, which becomes part of the vitreous phase as a result of boric acid melting, also increases the vitreous phase strength, and, consequently, the strength of the facing ceramics.

The dependences of ceramics water absorption on the amount of all cullet types used in the charge are also almost similar (Fig. 2).

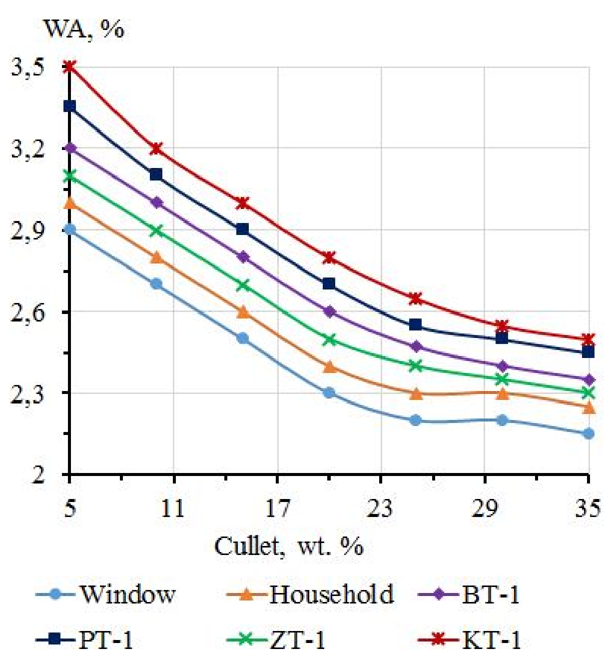

Figure 2. Water absorption dependence on cullet type and amount

As the resulted data proved, the considered property decreases alongside the increase of the cullet amount in the charge. This, like the case with the compressive strength, depends on the fact that the vitreous phase formed during firing, the cullet serves as its source, fills the pores and voids in the material depth. And the self-glazing effect transfers the remaining pores into the closed ones, where no water can penetrate. The intensity decrease of the water absorption reduction is explained by the fact that after the cullet introduction of more than 25 wt. % only the pores, where the melt cannot penetrate due to the insufficiently low viscosity, are not filled with the vitreous phase, so the water absorption is reduced only due to the proportion increase of the vitreous phase in the material depth.

The difference in the ceramics water absorption when different cullet types are applied, like in the case of strength, relates to the glass chemical composition. The cullet, where oxides dominate which reduce the viscosity (oxides of calcium, magnesium, sodium and potassium), allows you to get lower viscosity melt, which can fill smaller pores than the melt with higher oxides amount, which increase viscosity (oxides of silicon and aluminum). It should be noted that boron oxide introduced into the vitreous phase using boric acid reduces the melt viscosity, thus helping to reduce water absorption.

Since the maximum compressive strength is achieved at the introduction of 30 wt. % of cullet, the additional studies of the main performance properties of ceramics were conducted with this amount of additives, which results are presented in table 2.

Table 2: Facing ceramics properties depending on the cullet type

Ceramics property	Window glass cullet	Household glasscullet	Container glass cullet of various brands			
			BT-1	PT-1	ZT-1	KT-1
ρ, kg/m^3	2202	2167.2	2025.4	1924.6	1893	1872.8
σ_{cmp}, MPa	30.2	29.7	29.1	28.6	27.8	28.2
σ_{bnd}, MPa	6.3	6.2	6.1	6	5.8	5.9
WA, %	2.2	2.3	2.4	2.5	2.35	2.55
FR, cycle	69	66	63	60	64	59

Thus, the application of various cullet types together with boric acid makes it possible to produce facing ceramics, characterized with high density, strength and frost resistance at low water absorption, basing on low-plasticity clay. Herewith no significant difference in the properties of the ceramics samples produced using different cullet types is observed. However, the predominance of silicon, aluminum, calcium and magnesium oxides in the cullet composition allows producing denser and stronger material, and big amounts of calcium, magnesium, sodium and potassium oxides contribute to lower water absorption.

4. CONCLUSIONS

The research results revealed that facing ceramics with self-glazing effect can be produced basing on low-plasticity clay with the boric acid introduction in an amount of 2.5 wt. % and cullet in the amount of 30 wt. %. The strength characteristics of the resulting ceramics are sufficient for producing face bricks and stones corresponding to the M250-M300 grade in compliance with GOST 530-2012. The developed material frost resistance corresponds to not less grade than F50, thus meeting GOST 530-2012 requirements for face bricks and stones.

Therefore, the considered cullet types application in the developed charge composition, promotes possible disposal of this waste type in large quantities for producing high-quality construction products.

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