Use of Magnetic and Non-Magnetic Fractions of Coal Ash in the Preparation of Glazes from Waste Materials

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Summary

The paper deals with the use of magnetic and non-magnetic fractions of coal combustion ash for the preparation of ceramic glazes with waste glass. The aim of the study was to verify the suitability of these secondary raw materials for the production of so-called waste-derived glazes with various functional and aesthetic properties.

The physical (particle size distribution, specific surface area) and chemical properties of the individual materials were analysed experimentally. The proposed glaze mixtures were applied to two types of ceramic substrates and fired at 1060 °C and 1200 °C. Colour parameters and possible glaze defects after firing were also examined.

Based on the results, it can be concluded that magnetic fractions with a higher Fe_2O_3 content generate darker, more saturated shades suitable for dark decorative glazes. In contrast, non-magnetic fractions with higher Al_2O_3 content and lower iron content allow the formation of matte or lighter glazes. The function of waste glass contributes to good fusibility and enables the formation of light, glossy glazes thanks to its high SiO_2 content and the presence of fluxes Na_2O and CaO.

The study further confirms that the composition of the raw materials, their ratio, and the firing temperature significantly affect the colour and properties of the glazes. The findings support the use of coal ash and waste glass in the ceramic industry and offer an alternative to primary raw materials.

Keywords: *Coal ash, magnetic separation, glaze, secondary raw materials, Fe_2O_3, sustainable materials, recycling, ceramics.*

Introduction

Magnetic and non-magnetic fractions from coal ash can be utilized either as whole materials or as sources of valuable or undesirable components. Magnetic separation is often integrated into multi-component utilization processes for coal ash, typically dividing it into magnetic fractions, carbon-rich concentrates, and aluminosilicate components[1].

Unburned carbon levels in combustion residues can be highly variable, reaching over 30% in some domestic and industrial boilers[2]. Carbon-rich residues, originating from incomplete combustion of fossil fuels or biomass[3], have been investigated for applications such as graphite synthesis[4], adsorbents[5], and electrocatalysts[6]. Similarly, the non-magnetic fractions composed mainly of glass, quartz–mullite (or corundum), calcium silicate hydroxide, and salts[7] are being explored as alternative sources of alumina[8] or as precursors for zeolites[9], mullite[10], and Nosean[11], in response to the high cost and environmental burden of primary aluminum production.

Experimental part

Materials and experimental procedure

A mix of three coal ash materials (labelled as BULK CA) from coal combustion were collected from Castaldonovka dump in Horni Sucha (Czech Republic). The sampled coal ash material was dried at 105 °C for 3 hours (the weight difference was stable), where it was subsequently cooled in a desiccator and weighed. Subsequently, the ash sample was ground in a vibratory disc mill for 2 minutes and manually sieved to a size below 0.1 mm. BULK CA was subjected to dry manual magnetic separation with a breaking force of 25 kg. Magnetic separation was performed on 100 g of dry sample and a distance of 2 cm of the magnet from the sample. This process of magnetic separation created two fractions: a non-magnetic fraction (labelled as NF CA) and a magnetic fraction (labelled as MF CA).

The waste glass (labelled as WG) sample was obtained after the demolition of the Werk Arena station in Trinec (Czech Republic). A glass sample was also dried at the same temperature and for the same time as coal ash material. After drying, the glass sample was ground in a vibratory disc mill for 2 minutes and manually sieved to a size of 0.063 mm.

NF CA, MF CA and BULK CA were subsequently tested in ratios 1:0, 1:1 and 3:7 with waste glass for the formation of glazes. These three samples were used to compare the final appearance of the glaze and its changes based on the different chemical content of the mentioned fractions. The ratios were chosen based on the initial firings of the ceramics and selected based on the resulting coloration obtained.

Application of waste glazes were tested on two types of ceramic materials. The first ceramic substrate was commercial tile with the dimensions 10x10 cm. This material is designed for thermal expansion up to 1180 °C. These series of glazes are labelled as K1-K9 were firing at temperature of 1060 °C.

The second tested samples were commercial ceramic too with grain sizes ranging from 0 to 0.2 mm. The recommended firing temperature range is between 980 °C and 1250 °C. For this series was prepared disc with a diameter of 5 cm. This ceramic matrix was use for the series labelled as G1-G12 with final firing temperature of 1060 °C and 1200 °C. Both ceramic materials consisted mainly of SiO_2 (ceramic material designated as K = 57.58 wt. % and ceramic material designated as G = 54.36 wt. %). The difference was in the CaO content (K = 9.04 wt. % and G = 0.44 wt. %) and in the Al_2O_3 content (K = 20.51 wt. % and G = 28.98 wt. %).

The all glazes were applied on before fired ceramic and as application was used spraying method.

Characterization methods and accessories

Milling and homogenization of the raw materials was performed using vibratory disc mill BVM-2 (Brio Hranice s.r.o.). The firing process of glazed tiles was performed using laboratory furnace LAC (LAC s.r.o.).

The particle size distribution (laser diffraction method) and specific surface area (BET surface area method) of milled coal ash and waste white glass samples was determined using a Malvern Instrument device with the Aero method, covering a range of 0.1 – 10000 µm (Malvern Panalytical Ltd., Malvern, UK).

Colour measurements were carried out using a spectrophotometer (MiniScan EZ0828, HunterLab, model 45°/0°, small viewing area), based on CIEL**a**b* coordinates according to the CIE (Commission Internationale de l'Éclairage) system. 3 values were measured from different parts of the sample and then averaged.

The chemical composition of samples was determined by a method of energy-dispersive X-Ray fluorescence spectroscopy (ED-XRF) on the SPECTRO XEPOS (Spectro Analytical Instruments, Kleve, Germany).

Results and discussions

Particle size is important information for glaze creation. The resulting volume-based particle size distribution curve (Figure 1) for BULK CA sample shows a log-normal distribution with the following size parameters: Dv10 = 1.54 µm, Dv50 = 6.29 µm and Dv90 = 22.3 µm. Dv10, Dv50 and Dv90 values indicate that most of the particle volume is in the range of 1.5 – 22 µm. The coal ash sample shows a broad and non-uniform particle size distribution with a dominance of fine fractions and a small proportion of larger particles. The specific surface area (1139 m²/kg) indicates a significant fineness of the particles, which may be important from the point of view of reactivity or use in ceramics, concrete or other binders.

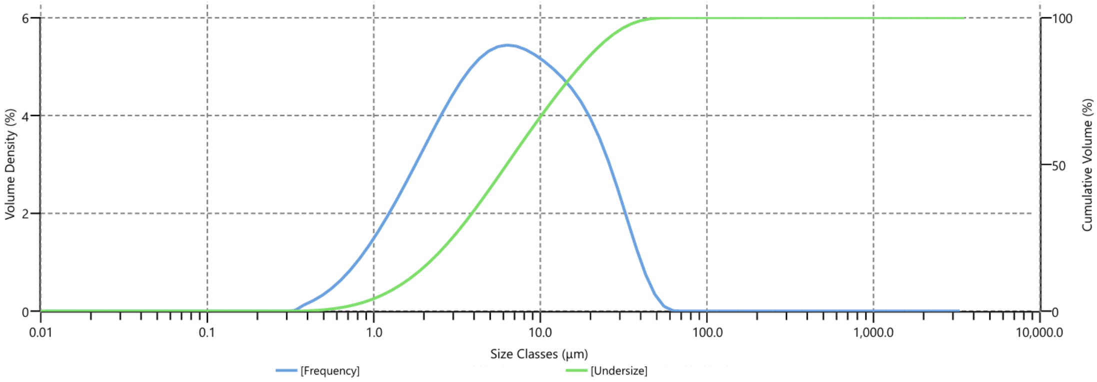


Figure 1: Particle size distribution analyses of BULK CA

The resulting volume-based particle size distribution curve (Figure 2) for the waste white glass sample exhibits a log-normal profile, characterized by the following key parameters: Dv10 = 2.81 µm, Dv50 = 15.3 µm, and Dv90 = 47.8 µm. These values indicate a broad particle size distribution, reflecting a heterogeneous glass fraction dominated by medium-sized particles, with a substantial presence of both fine and coarse fractions. The high specific surface area (627.1 m²/kg) further supports the conclusion that the fine particle fraction significantly influences the material's reactivity. This particle size profile is well-suited for technical applications such as glass-ceramic production and glaze formulation.

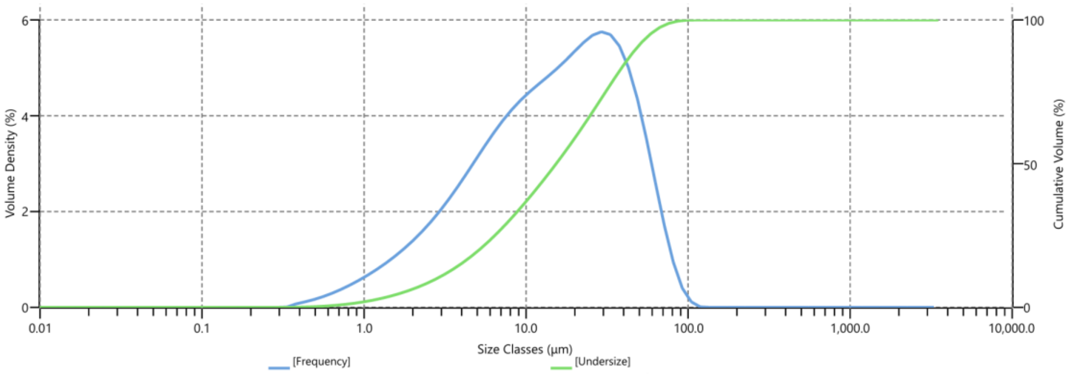


Figure 2: Particle size distribution analyses of WG

In the production of ceramic glazes, it is crucial to understand the chemical composition of raw materials, as they affect the fusibility, structure, and aesthetic properties of the final glaze. The following materials were examined in this study (Table 1): bulk coal ash (BULK CA), magnetic fraction of coal ash (MF CA), non-magnetic fraction of coal ash (NF CA) and waste glass (WG).

Table 1: Chemical composition of waste materials tested by XRF analysis

Oxides (wt. %)	**Materials** (wt. %)			
	Bulk CA	**MF CA**	**NF CA**	**WG**
Na_2O	0.25	0.30	0.23	11.64
MgO	2.02	2.34	2.04	3.13
Al_2O_3	18.06	20.68	19.85	0.97
SiO_2	34.64	39.04	36.66	68.06
P_2O_5	0.32	0.29	0.25	-
SO_3	1.2	1.09	1.24	0.53
Cl	0.01	0.01	0.01	0.13
K_2O	2.64	2.71	2.56	0.56
CaO	5.69	3.10	2.77	13.57
TiO_2	0.9	0.92	0.83	0.12
Cr_2O_3	0.07	0.03	0.03	-
MnO	0.41	0.16	0.12	-
Fe_2O_3	11.85	12.42	8.50	0.51
NiO	0.02	0.02	0.02	-
CuO	0.02	0.02	0.02	-
ZnO	0.04	0.04	0.03	0.05
As_2O_3	-	0.01	0.01	-
Rb_2O	0.02	0.2	0.02	-
SrO	0.05	0.05	0.05	0.02
ZrO_2	-	0.03	0.02	0.02
Y_2O_3	0.01	0.1	0.01	-
LOI-Flux	21.74	16.72	24.68	0.69

All three types of coal ash contain significant amounts of silicon dioxide (SiO_2 ranging from 34.64 wt. % to 39.04 wt. %) and aluminium oxide (Al_2O_3 ranging from 18.06 wt. % to 29.85 wt. %), which together form the basis of the glassy matrix and ensure the structural stability of the glaze. A common feature among them is also the presence of fluxing agents such as CaO, K_2O, and MgO, which help lower the melting temperature and influence the gloss or flow of the glaze during firing.

However, the individual fractions differ in their chemical composition and therefore in their technological behaviour. BULK CA has a balanced content of iron (Fe_2O_3 - 11.85 wt. %), fluxes, and loss on ignition (LOI – 21.74 wt. %), making it suitable for use in darker or technical glazes where potential coloration is not an issue. The magnetic fraction (MF CA) shows the highest content of iron oxide (12.42 wt.%) and is therefore most suitable for dark and matte glazes, where iron can also serve as a colouring component. In contrast, the non-magnetic fraction (NF CA) is characterized by a significantly higher aluminium oxide content (29.85 wt. %) and a lower iron content (8.50 wt. %), making it a suitable material for matte, satin, or more light orange glazes.

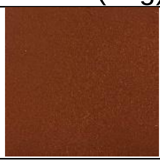
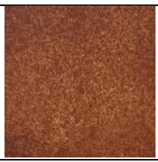
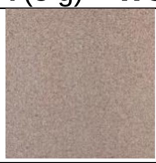
The efficiency of magnetic separation of coal ash was determined based on the weight and magnetic content before and after separation. From 100g of input material with a magnetic content of 11.85 wt. %, there were 35 g of magnetic fraction with a magnetic content of 12.42 wt. %, which corresponds to an efficiency of approximately 36.7%. This value can be considered low but expected from the point of view of the use of manual magnetic separation. Manual magnetic separation was chosen as a fast and accessible method of magnetic separation, which is the most economical and time efficient. To increase the efficiency of magnetic content, wet magnetic separation and vibrofluid magnetic separation will be tested in further research.

WG was characterized by a very high content of silicon dioxide (SiO_2 – 68.06 wt. %) and a high proportion of fluxes, especially Na_2O (11.64 wt. %) and CaO (13.57 wt. %). Its low content of Al_2O_3 (0.97 wt. %) and LOI (0.69 wt. %) make it a chemically stable and easily fusible raw material. Thanks to its chemical purity and absence of colouring oxides, it is an ideal candidate for the preparation of clear, glossy, or light-coloured glazes.

The colour was represented using the CIE L**a**b* colour space. In this system, the L* coordinate indicates the brightness of the sample, where higher positive values (up to a maximum of 100) correspond to lighter or white shades, and lower values (down to a minimum of 0) indicate darker or black shades. The a* coordinate defines the green (negative) to red (positive) axis, while the b* coordinate defines the blue (negative) to yellow (positive) axis. The L**a**b* values measured for the analysed glazes are shown in Table 2. These CIELab coordinates (L*, a*, b*) were subsequently converted into HEX codes[12,13], a different format for representing colours.

Table 2 presents series K1-K9, which contain prepared glazes from BULK CA, NF CA, MF CA and WG. From the optometric evaluation, it can be stated that the resulting glazes are of reddish-brown tones. The resulting glazes have a matte finish. The ratio of individual components changes the final colour.

Table 2: Colour analyses of prepared glazes K1-K9 at a temperature of 1060 °C and their CIELab coordinates

1060 °C		
K1 **BULK CA** (10g)	**K2** **NF CA** (10g)	**K3** **MF CA** (10g)
		
L* = 52.20	L* = 49.91	L* = 46.24
a* = 21.51	a* = 18.05	a* = 17.57
b* = 31.75	b* = 21.30	b* = 21.84
K4 **BULK CA** (5 g) **+ WG** (5 g)	**K5** **NF CA** (5 g) **+ WG** (5 g)	**K6** **MF CA** (5 g) **+ WG** (5 g)
		
L* = 55.37	L* = 54.50	L* = 51.41
a* = 19.52	a* = 21.28	a* = 20.96
b* = 29.16	b* = 32.21	b* = 29.75
K7 **BULK CA** (3 g) **+ WG** (7 g)	**K8** **NF CA** (3 g) **+ WG** (7 g)	**K9** **MF CA** (3 g) **+ WG** (7 g)
		
L* = 70.29	L* = 74.58	L* = 69.89
a* = 9.17	a* = 8.30	a* = 9.33
b* = 19.32	b* = 18.91	b* = 19.81

The darkest glaze with using 100 % coal ash (**K1-K3**) was sample K3 (MF CA) with coordinates L* = 46.24 and a* = 17.57, and with HEX code #94624A. Its saturation and lightness were 33.3% and 43%, respectively. The lightest glaze using 100 % coal ash was K1 (BULK CA) with coordinates L* = 52.20 and a* = 21.51 with HEX code #ad6d47, and with a saturation of 41.8% and a lightness of 47.8%.

Glazes **K4-K6** were prepared in a 1/1 ratio (CA/WG). In the case of glaze K6 (MF CA + WG), dark medium orange tones were observed, while in K4 (BULK CA + WG) and K5 (NF CA + WG), moderate orange tones were observed. The glazes mentioned above K4 and K5 showed similar colour properties. K4 with HEX code #B37753 with coordinates L* = 55.37 and a* = 19.52 had a saturation of 38.7% and a lightness of 51.4%. K5 with HEX code #b4734c with coordinates L* = 54.50 and a* = 21.28 had a saturation of 40.9% and a lightness of 50.2%.

Glaze samples **K7-K9** exhibited a lighter colour shade compared to the others (K1-K6), as indicated by the l parameter L. These glazes also displayed slightly desaturated orange tones. These glazes were prepared in a 3/7 ratio (CA/WWG). The darkest glaze was K9 (MF CA + WG) with HEX code #C8A487 with coordinates L* = 69.89 and a* = 9.33 and with saturation of 37.1 % and a lightness of 65.7 %. The lightest glaze of the three was K8 (NF CA + WG) with HEX code #d3b195 with coordinates L* = 74.58 and a* = 8.30, and with a saturation of 41.3% and a lightness of 70.6%. The lighter shade of the K8 glaze compared to K7 may be due to the higher content of Al_2O_3 and SiO_2 (Table 2) in NF CA compared to the BULK CA sample.

It was possible to see that there were no visible surface defects on the glazes. It can be said that the proposed firing temperature for this series was appropriate. Considering the expansion of the prepared glazes and ceramic shards, they were appropriately selected.

A significant colour contrast was observed (Table 3) when using the second ceramic tile (which enabled to use a higher temperature without breaking the ceramics) at temperatures of 1200 °C and 1060 °C for glazes samples **G1-G12**.

Table 3: Colour analyses of prepared glazes G1-G12 at a temperature of 1060 °C and 1200 °C and their CIELab coordinates

1200 °C		**1060 °C**	
G1 **NF CA** (10g)	**G2** **MF CA** (10g)	**G3** **NF CA** (10g)	**G4** **MF CA** (10g)
			
L* = 36.06	L* = 28.18	L* = 53.41	L* = 49.92
a* = 6.09	a* = 4.35	a* = 20.16	a* = 19.89
b* = 13.44	b* = 5.84	b* = 29.77	b* = 28.27
G5 **NF CA** (5 g) **+ WG** (5 g)	**G6** **MF CA** (5 g) **+ WG** (5 g)	**G7** **NF CA** (5 g) **+ WG** (5 g)	**G8** **MF CA** (5 g) **+ WG** (5 g)
			
L* = 53.26	L* = 28.76	L* = 46.57	L* = 37.58
a* = 6.91	a* = 21.33	a* = 11.01	a* = 16.66
b* = 46.90	b* = 49.29	b* = 12.69	b* = 22.39
G9 **NF CA** (3 g) **+ WG** (7 g)	**G10** **MF CA** (3 g) **+ WG** (7 g)	**G11** **NF CA** (3 g) **+ WG** (7 g)	**G12** **MF CA** (3 g) **+ WG** (7 g)
			
L* = 68.85	L* = 65.38	L* = 72.28	L* = 64.62
a* = 3.94	a* = 6.67	a* = 10.30	a* = 12.84
b* = 20.72	b* = 39.53	b* = 23.14	b* = 21.69

Darker shades were observed using 100% coal ash at temperatures of 1200 °C (**G1** and **G2**) and 1060 °C (**G3** and **G4**). Samples G1 and G2 are the only ones in matte; the other samples in this series are glossy. It cannot be clearly said that temperature has a direct effect on the change in colour of the samples. A very dark, desaturated orange tone was observed in the case of glaze G1 (1200 °C). Glaze G1 (NF CA) with HEX code #665140 had coordinates L* = 36.06 and a* = 6.09, and a saturation of 22.9% and a lightness of 32.5%. A very dark greyish orange tone was observed in the case of glaze G2 (1200 °C). Glaze G2 (MF CA) with HEX code #4D403A had coordinates L* = 28.18 and a* = 4.35, and saturation of 14.1 % and a lightness of 26.5%. Dark moderate orange tone was observed in the case of glaze G3 (1060 °C). Glaze G3 (NF CA) with HEX code #AE714D had coordinates L* = 53.41 and a* = 19.89 and saturation of 38.6 % and a lightness of 49.2 %. Also, a dark moderate orange tone was observed in the case of glaze G4 (1060 °C). Glaze G4 (MF CA) with HEX code #A36948 had coordinates L* = 49.92 and a* = 20.16 and with a saturation of 38.7 % and a lightness of 46.1%.

Subtler dark colours of glazes were observed when using a 1/1 ratio (5 and 5 grams) of NF CA or MF CA with WG (**G5-G8**) at temperatures of 1060 °C and 1200 °C. Dark orange (brown tone) tone was observed in the case of glaze G5 (1200 °C). Glaze G5 (NF CA + WG) with HEX code #9F792A had coordinates L* = 53.26 and a* = 6.91. Its saturation and lightness were 58.2% and 39.4%, respectively. Very dark orange (Brown tone) tone was observed in the case of glaze G6 (1200 °C). Glaze G6 (MF CA + WG) with HEX code #6C3300 had coordinates L* = 28.76 and a* = 21.33, and saturation of 100% and a lightness of 21.2%. Mostly desaturated dark orange tone was observed in the case of glaze G7 (1060 °C). Glaze G7 (NF CA + WG) with HEX code #88675A had coordinates L* = 46.57 and a* = 11.01. It had a saturation of 20.4 % and a lightness of 44.3 %. Dark moderate orange tone was observed in the case of glaze G8 (1060 °C). Glaze G8 (MF CA + WG) with HEX code #7B4D35 had coordinates L* = 37.58 and a* = 16.66, and saturation of 39.8% and a lightness of 34.5%.

The lightest glazes (**G9-G12**) were created using a ratio of 3/7 (3 and 7 grams) of NF CA or MF CA with WG at temperatures of 1060 and 1200 °C, a result confirmed by the chemical composition of the materials used (high silica content). Slightly desaturated orange was observed in the case of glaze G9 (1200 °C). Glaze G9 (NF CA + WG) with HEX code #BDA483 had coordinates L* = 68.85 and a* = 3.94, and saturation of 30.5% and a lightness of 62.7%. A moderate orange tone was observed in the case of glaze G10 (1200 °C). Glaze G10 (MF CA + WG) with HEX code #C09957 had coordinates L* = 65.38 and a* = 6.67, and a saturation of 45.5 % and a lightness of 54.7 %. A slightly desaturated orange tone was observed in the case of glaze G11 (1060 °C). Glaze G11 (NF CA + WG) with HEX code #D2A988 had coordinates L* = 72.28 and a* = 10.30 and a saturation of 45.1% and a lightness of 67.8%. Also, a slightly desaturated orange tone was observed in the case of glaze G12 (1060 °C). Glaze G12 (MF CA + WG) with HEX code #C09477 had coordinates L* = 64.62 and a* = 12.84. Its saturation and lightness were 36.7% and 61%, respectively.

Increasing the concentration of ferric oxide (Fe_2O_3) in glaze compositions significantly affects the final optical properties of glazes. According to international research[14-17] that supports this study, increasing Fe_2O_3 content leads to a systematic change in glaze colour. In an oxidising atmosphere, a colour transition was observed—from light cream shades (at low concentrations) through yellow and brown tones (around 5%), to dark brown and even black tones at concentrations above 7%. This colour shift results from changes in the oxidation state of iron and its distribution within the surface layer of the glaze. The presence of ferric oxide promotes the formation of pigment structures and increases colour intensity depending on its concentration. Another important factor is temperature: at higher firing temperatures (1100 – 1200 °C), more intensive dissolution and redistribution of iron occur, which enhances its pigmentation effect.

Regarding surface defects, the samples did not show standard defects such as craters, bubbles, or cracks., the samples are compatible with the ceramic ceiling, and the increase in temperature has a positive effect on the resulting glaze colour.

Further important tests will be carried out to evaluate the fundamental technical parameters of the examined glazes, such as surface hardness, surface roughness, abrasion resistance, adhesion to the ceramic substrate, thickness, and the achieved uniformity and homogeneity of the glaze layers. These properties will subsequently be compared with those of glazes produced from primary raw materials to assess the extent to which recycled or alternative components can maintain or improve the functional and aesthetic characteristics of the final glazed surface.

Conclusions

The present study has demonstrated the potential of utilizing magnetic and non-magnetic fractions of coal combustion ash, in combination with waste glass, for the preparation of ceramic glazes. The results confirmed that the chemical composition of the ash fractions significantly influences the final glaze properties. Magnetic fractions, characterized by higher Fe_2O_3 content, produced darker and more saturated tones suitable for decorative applications, while non-magnetic fractions, with higher Al_2O_3 and lower Fe_2O_3 content, enabled the formation of lighter or matte glazes. Waste glass, owing to its high SiO_2 and flux content, contributed to enhanced fusibility and the development of glossy glazes.

The firing temperature was shown to be a critical factor, as it influenced both the optical appearance and surface quality of the prepared glazes. Across all tested compositions, no major surface defects were observed, and the glazes demonstrated compatibility with ceramic substrates. These findings confirm that coal ash and waste glass represent valuable secondary raw materials that can partially substitute primary raw materials in glaze production. Their utilization not only supports the development of sustainable ceramic technologies but also contributes to the recycling of industrial by-products, offering both environmental and economic benefits.

From a broader perspective, this research highlights the feasibility of integrating industrial waste into high-value ceramic products, thus promoting circular economy principles. Future studies should focus on scaling up the proposed glaze formulations for industrial applications, optimizing the ratio of coal ash fractions to waste glass for tailored colour and surface effects, and evaluating long-term durability and leaching behaviour to ensure environmental safety. Other important tests such as surface hardness, surface roughness, abrasion resistance, adhesion to the ceramic substrate, and thickness of glaze layers will also be performed. In addition, further exploration of advanced firing techniques, as well as the use of other industrial by-products, could expand the palette of functional and aesthetic glaze properties.

Overall, this work provides a foundation for developing environmentally responsible and economically viable ceramic products based on recycled materials.

List of symbols

BULK CA – Bulk Coal Ash
CIELab / CIELab* – colour model defined by the International Commission on Illumination
ED-XRF – Energy-Dispersive X-Ray Fluorescence
HEX – Hexadecimal colour coding
LOI – Loss on Ignition
MF CA – Magnetic Fraction of Coal Ash
NF CA – Non-magnetic Fraction of Coal Ash
WG – Waste Glass

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Využití magnetických a nemagnetických frakcí uhelného popela pro přípravu glazury z odpadních materiálů

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Abstrakt

Příspěvek se zabývá využitím magnetických a nemagnetických frakcí popílku ze spalování uhlí pro přípravu keramických glazur s odpadním sklem. Cílem studie bylo ověřit vhodnost použití těchto druhotných surovin pro přípravu tzv. odpadních glazur s různými funkčními a estetickými vlastnostmi.

Experimentálně byly analyzovány fyzikální (distribuce velikosti částic, specifický povrch) i chemické vlastnosti jednotlivých materiálů. Navržené mixy glazur byly aplikovány na dva typy keramických podkladů a vypalována na teploty 1060 °C a 1200 °C. Rovněž byly analyzovány barevné parametry a případné defekty glazur po výpalu.

Na základě výsledků, lze říci, že magnetické frakce s vyšším obsahem Fe_2O_3 generují tmavší, sytější odstíny vhodné pro tmavé dekorační glazury. Naproti tomu nemagnetické frakce s vyšším obsahem Al_2O_3 a nižším obsahem železa umožňují tvorbu matných nebo světlejších glazur. Funkce odpadního skla přispívá k dobré tavitelnosti a umožňuje tvorbu světlých, lesklých glazur díky vysokému obsahu SiO_2 a tavidel Na_2O a CaO.

Studie dále potvrzuje, že složení vstupních surovin, jejich poměr a teplota výpalu významně ovlivňují barvu a vlastnosti glazur. Zjištěné výsledky podporují využití popílku a odpadního skla v keramickém průmyslu a nabízejí alternativu k primárním surovinám.

Klíčová slova: *Uhelný popel, magnetická separace, glazura, druhotné suroviny, Fe_2O_3, udržitelné materiály, recyklace, keramika.*