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Glass Ceramics Composites Fabricated from Coal Fly Ash and Waste Glass

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INTRODUCTION

Great quantities of coal ash are produced in thermal power plants which present a double problem to the society: economical and environmental. This waste is a result of burning of coal at temperatures between 1100-1450^{0}C. Fly ash available as fine powder presents a source of important oxides SiO_2, Al_2O_3, Fe_2O_3, MgO, Na_2O, but also consist of small amount of ecologically hazardous oxides such as Cr_2O_3, NiO, MnO. The combination of the fly ash with waste glass under controlled sintering procedure gave bulk glass-ceramics composite material. The principle of this procedure is presented as a multi barrier concept (1). Many researches have been conducted the investigations for utilization of fly ash as starting material for various glass–ceramics production (2-4). Using waste glass ecologically hazardous components are fixed at the molecular level in the silicate phase and the fabricated new glass-ceramic composites possess significantly higher mechanical properties.

The aim of this investigation was to fabricate dense glass ceramic composites using fly ash and waste glass with the potential for its utilization as building material.

RESULTS

Fly ash from the thermal power plant REK Bitola, Republic of Macedonia (from forth zone of electro filter with particle size lower than 63μm) and a type of waste glass from laboratory inventory (particle size lower than 63μm) were used as raw materials for this investigation. The compacts were codded as follows: fly ash - FA, waste glass - WG, FA50WG – glass ceramics composite with glass content from 10 to 50wt.% i.e. FA10WG – composite consisted of fly ash with 10wt.% waste glass). Chemical analysis of the fly ash was carried out by X-ray fluorescence (model ARL 9900XP) and the chemical composition of the waste glass was declared from the manufacturer Pyrex (5). The chemical compositions of the investigated waste materials are given in Table 1.

Table 1. Chemical compositions of the industrial wastes

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	B_2O_3	LOI	Σ
FA [wt%]	49.51	17.62	7.91	13.77	3.36	0.69	1.46	3.52	/	1.57	99.41
WG [wt%]	83.34	1.33	/	0.03	/	4.08	0.04	/	11.19	/	100

Fly ash belongs to the silicates due to the evident presence of the SiO_2, Al_2O_3 and Fe_2O_3 as basic oxides constituencies. The level of CaO and SO_3 are relatively high, while the level of MgO and other alkali metal oxides are typical as the other ashes.

The morphology of the fly ash is presented in figures 1. It is evident the presence of primary spherical particles with dimension cca 10μm and particles with irregular geometry with dimensions from 5 to 20μm. Also the presence of agglomerates is evident. The particles of waste glass are with irregular geometry and dimensions from 10 to 60μm, figure 2.

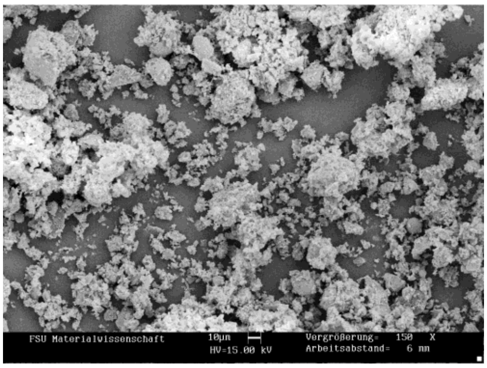

Figure 1. SEM micrograph of the FA, (bar 10μm)

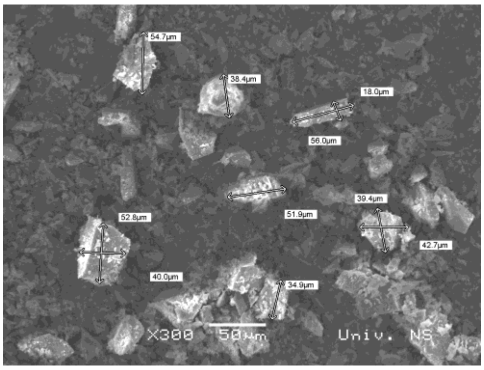

Figure 2. SEM micrograph of the WG, (bar 50μm)

Glass-ceramics composites were fabricated by adding waste glass in quantity from 10 to 50wt.% to the fly ash. One of the reasons was to increase mechanical properties of the composites and secondly to encapsulate the particles of industrial wastes into matrix. Prior to the consolidation the milling and homogenization of the fly ash and waste glass were realized in the planetary mill (Fritsch pulverisette 5) during 60 min. Pressing of the samples was performed by uniaxial press (Weber Pressen KIP 100) at P=45 MPa using PVA as a binder. Dense composites with different densities were obtained by varying the sintering temperatures: 900, 1000 and 1050^{0}C with the holding time at a maximum temperature of 1 hour. The applied heating rate was 10^0/min. FA50WG composites sintered at 1000^{o}C and 1050^{0}C were deformed. The sintered glass ceramics composites were tested using three point bending tester (Netzsch 401/3) to determine mechanical properties (bending strength and E-modulus).
According the obtained results in this investigation the whole spectrum of the glass ceramics composites were fabricated, but the properties (density, bending strength, E-modulus, porosity and linear shrinkage) of WG (sintered at 700^{0}C), FA and the optimal glass ceramics composites (FA10WG, FA40WG) sintered at 1000^{0}C (chosen as optimal sintering temperature) are presented in Table 2.

Table 2. Sintering temperature, density, bending strength, E –modulus, porosity, and linear shrinkage of fly ash, waste glass and the optimal glass ceramics composites

Compacts	**Sinter.temp./ time[^{0}C/h]**	ρ **[g/cm^3]**	σ **[MPa]**	**E [GPa]**	Θ **[%]**	**ΔL/L [%]**
FA	1000/1h	1.433	9.41	4.90	43.69	1.96
WG	700/1h	2.233	69.08	27.31	14.43	15.77
FA10WG	1000/1h	1.470	17.98	7.34	42.21	3.05
FA40WG	1000/1h	2.214	63.62	32.31	10.65	13.84

It is evident that glass addition influenced on the incensement of the mechanical properties. Namely, the bending strength of FA is 9.41MPa, but for the glass ceramics composites FA10WG and FA40WG it increased to 17.98MPa and 63.62MPa, respectively. The E-modulus for the composites FA10WG and FA40WG increased to 7.34 and 32.3GPa, respectively in comparison to the pure FA (4.90GPa). The porosity of the FA compacts and FA40WG composites decreases from 43.69 to 10.65%, respectively and the shrinkage increased from 1.96 to 13.84% .

The microstructure of the fractured surface and EDS analysis of the FA10WG composite are presented in figure 3.

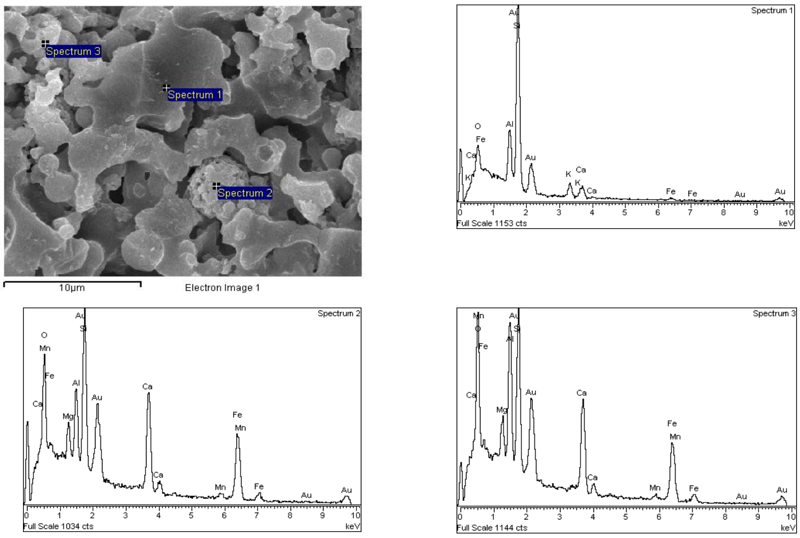

Figure 3. SEM micrograph and EDS spectrums (1-3) of composites FA10WG, t=1000°C

The fractured surface of the FA10WG composite is granular. It is evident presence of the liquid glassy phase, but also recognisable grains from the original morphology of the FA particles. EDS analysis confirmed that point 2 and point 3 correspond to the FA composition and the point 1 could be characterized as the region of the glassy phase.

Figure 4 shows that the microstructure of the fractured surface of the glass-ceramic FA40WG is homogeneous and smoother in comparison to the FA10WG composite. There are no recognisable grains from the FA and they are well encapsulated in the silica matrix. There is significant formation of closed spherical pores with dimensions between 5-10µm. The formation of the spherical pores is connected with softening of the glassy phase and evolution of gas (6). According to the similarity of the peaks (1-6) from the EDS analysis of glass ceramics composite FA40WG it can be concluded that FA particles are uniformly distributed in the glassy matrix.

CONCLUSIONS

As a general it can be concluded that it is possible to produce dense glass-ceramic composites using high percentage of coal fly ash and waste glass. The new glass-ceramic composites possess significantly higher mechanical properties which make them suitable for a wide range of application in the building industry.

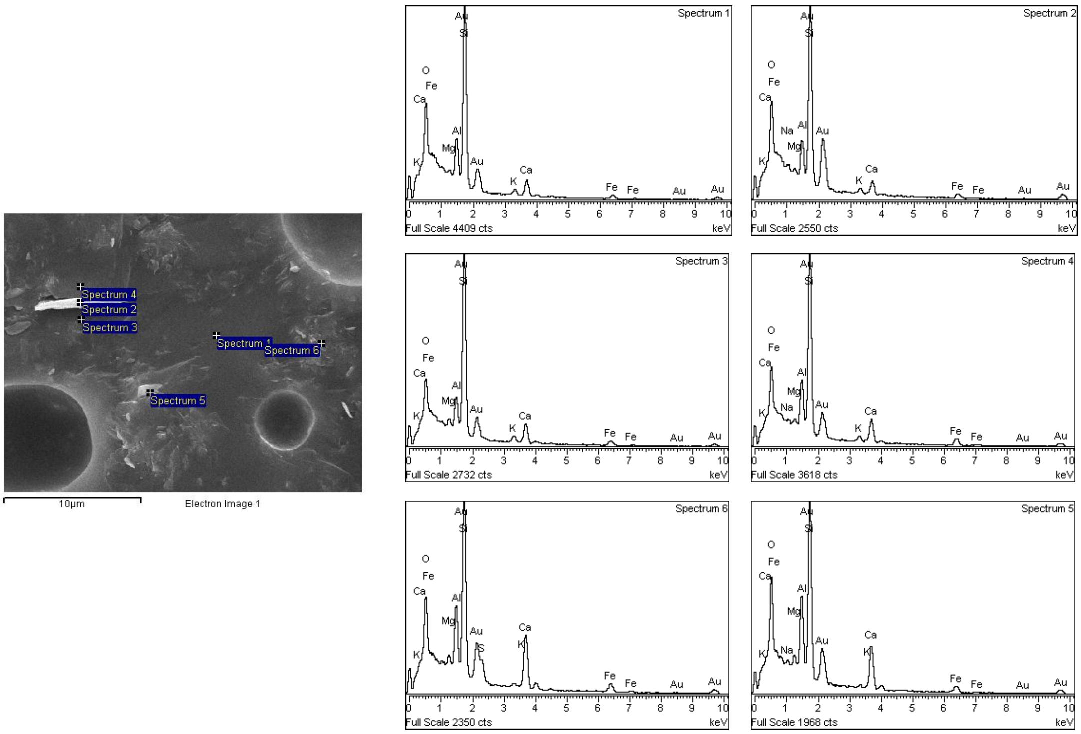

Figure 4. SEM micrograph and EDS spectrums (1-6) of composites FA40WG, t=1000^{o}C

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