APPLICATION OF ALUMINIUM DROSS AND GLASS WASTE FOR PRODUCTION OF EXPANDED CLAY AGGREGATE

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ABSTRACT

This research provides possibilities to reuse solid waste from aluminium scrap recycling factories and municipal solid waste (MSW) container glass for the production of lightweight aggregates. The aluminium dross residue is increasing along with the increase in the aluminum production. Similarly the problem of container glass rational utilization is a topical problem over the world. The presented research is focused to solve problems concerning to both industrial and municipal waste collection.
The production of expanded clay aggregate was simulated in the laboratory with pilot rotary furnace and electric furnace. Expanded clay aggregate was produced with different glass waste: aluminium dross: clay mix ratios, where aluminium dross acted as an extra pore-forming agent and glass waste as a fluxing agent. Pore structure was abundant ranging from irregular to spherical, resulting in low apparent density values, which directly was affected with the firing temperature up to 1200 °C and time, controlled with the rotation velocity and furnace incline.
The main objectives of this experimental study are to examine the effects of aluminium dross and glass waste addition to the physical and microstructure properties of expanded clay aggregate sintered on a laboratory scale.

Key words: expanded clay aggregate, glass waste, aluminium dross

INTRODUCTION

Expanded clay aggregates (ECA) occur in nature (pumice, volcanic tuffs, etc.) or they can be industrially manufactured. For their production two mechanisms are necessary to occur simultaneously during firing (Ehlers, 1958): first, the development of a highly viscous glassy phase, able to entrap the formed gases, and second, the production of gases. At this temperature, the material is in pyroplastic condition and the gases do not escape readily, allowing the aggregate to expand. The result is a cellular structure comprised of pores distributed within the mass.
The consumption of aluminium recycling waste has been rising continuously worldwide, which is great stimulus for developing a non-waste technology (Shinzato and Hypolito 2005; Shen and Forsberg 2003; Lucheva et al. 2005). Aluminium dross represents residue from primary and secondary aluminium production. Drosses are classified according to the aluminium metal content into white and black dross. White dross has a higher metal aluminium content and it is produced from primary and secondary aluminium smelters, whereas black dross has a lower metal content and is generated during aluminium recycling (secondary industry sector). Black dross typically contains a mixture of aluminium oxides and slag with recoverable aluminium content ranging between 12–18% (Gil, 2005; Shen and Forssberg, 2003; Lucheva et al., 2005). The conventional rotary furnaces heated with a fuel or a gas burner are used to recover the extra aluminium from black or white dross. This treatment process produces the non-metal product called aluminium recycling waste containing alumina, salts, impurities and a little amount (3–5%) of metallic aluminium. There have been previous research studies which investigate the use of aluminium recycling waste (non-metal product NMP) generated from dross processing (Bajare et al., 2008; 2010; Bajare and Korjakins, 2009). NMP was used as a pore formatting agent. It was concluded that NMP is suitable for production of ECA with the density from 0.4 to 0.7 g/m3. The density of ECA noticeable depends on two factors: the amount of added aluminium recycling waste and sintering temperature.
A major component in municipal solid waste (MSW) is container glass, even though it is relatively easy to separate (Karamberi and Moutsatsou, 2005). Glass is included in the EU Thematic Strategy on the Prevention and Recycling of Waste rates set for the Member States. By 2020, 50% by weight of glass will have to be recycled in Latvia. In 2007 the rate was 34.5% (EUROPA, 2007).
Glass has been successfully used as a binder and fluxing agent in ceramics and bricks, as it lowers the softening temperature, firing time and energy consumption (Barbieri et al., 1997, 2000; Nagaraj and Ishikawa, 1999; Ducman et al., 2002; Karamberi and Moutsatsou, 2005).

The main objective of this experimental study is to examine the effects of the waste glass usage as a fluxing agent which lowers the sintering temperature on the physical and microstructural properties of ECA.

MATERIALS AND METHODS

In the current study, ECA were produced from clays with high content of carbonates, aluminium dross and glass waste in different compositions.

Clay

The clay used in the experiments is a natural raw material. It is plastic clay composed of quartz, calcite, dolomite, illite, kaolonite and anorthoclase, according to the X-ray diffraction (XRD) analysis. Dolomite, as a mineral, has been determined in the average proportion of 21.6 % in the clay composition. The chemical composition of clay is given in Table 1. According to the analysis, the clay used in the experimental studies is typical carbonate clay.

Aluminium dross (NMP)

According to the element analysis resulted from inductive coupled plasma optical spectrometry (ICP-OES), atomic absorption spectroscopy (AAS) and potentiometer titration analyses, the NMP contains: aluminium (Al) – 34.4%, silicon (Is) – 4.4% magnum (Mg) – 2.4%, calcium (Ca) – 1.32%, sodium (Na) – 1.69%, potassium (K) – 2.31%, sulphur (S) – 0.07%, chlorine (Cl) – 4.23, ferric (Fe) – 3.6%, copper (Cu) – 0.99%, zinc (Zn) – 0.6%.

These data correspond to the chemical composition of aluminium recycling waste, which is given in Table 1. From the point of the chemical composition the analyzed wastes contain also aluminium nitride (AlN) - on average 5%, aluminium chloride – ($AlCl_3$) - on average 3%, potassium and sodium chloride (KCl +NaCl) – totally 5% and ferric sulphide ($FeSO_3$) - on average 1%.

The mineralogical composition of the NMP is determined by using the XRD analysis. According to the analysis data, the NMP contains corundum (Al_2O_3), silica (SiO_2), ferric sulphite ($FeSO_3$), aluminium chloride ($AlCl_3$), calcium ferric oxide ($Ca(FeO_3)$), calcium, magnesium or ferric carbonate ($Ca(Mg,Fe)(CO_3)_2$), gibbsite ($Al(OH)_3$), spinel ($FeAl_2O_4$) or ($MgAl_2O_4$) and aluminium nitride (AlN).

Waste glass

Waste glass derived from bottles and window glass was crushed and ground to a fineness of less than 100 µm. Its chemical composition is given in Table 1.

Table 1

Basic chemical composition of clay and NPM and waste glass (amount %)

	Clay	NMP	Waste glass
Al_2O_3	14.34	63.19	1-3
SiO_2	50.22	7.92	70-74
CaO	8.54	2.57	5-11
SO_3	0.07	0.36	-
TiO_2	0.56	0.53	-
Na_2O	0.43	3.84	12-16
K_2O	3.09	3.81	-
MgO	3.07	4.43	1-3
Fe_2O_3	5.74	4.54	-

It is clear from the chemical analysis that this waste consists of high amounts of fluxing oxides such as Na_2O and CaO.

Preparation and synthesis of lightweight expanded clay aggregates (ECA)

Clay was mixed with NMP and glass waste in different ratios. The glass waste mass ratio in the composition was from 5-14%, NMP mass ratio was 14-35%. The raw materials were ground and mixed together in the planetary ball mills. The average particle size of the mixes was 54 µm. Plastic mass was prepared by adding 20–25% water and rounded by shaping operation. The prepared aggregates were dried in an oven at 105°C to avoid reaction between aluminium recycling waste and water used for preparation of the plastic mass. Green aggregates were treated at sintering temperatures from 1110 to 1250°C in an electrical furnace. The rate of temperature increase in the furnace was kept constant as 15°C/min. The gasiform substances and new minerals from NMP like spinel and alumina are originated during the heat treatment process of NMP. The phenomena of origination of gasiform substances during the heat treatment of NMP should be used as a pore creator for obtaining a porous structure of lightweight ceramic aggregates (ECA). As the hazardous compounds of NMP are transformed into new ones, non-hazardous compounds, NMP does not have the toxic nature anymore and it becomes environmental friendly and it can be a constituent part of a new, environmental friendly material (Bajare et al., 2009). Meanwhile, waste glass is used as a fluxing agent lowering the sintering temperature. After production the physical property, like water absorption after 24 h, open porosity and bulk density tests were conducted on the aggregate samples. The microstructure of the lightweight aggregates produced at different temperatures was observed by an optical microscope.

RESULTS AND DISCUSSION

The physical properties of ECA granules produced in the present study are shown in Table 2. According to the test results, the sintering temperature decreased with the increase in the waste glass amount in the composition.

One of the most important properties of ECA granules is the bulk density which in this present study is between 0,465 and 1,090 g/cm^3.

Table 2.

Physical properties of ECA sintered at different temperatures

Composition ratio (waste glass:NMP: clay)	Sintering temperature (°C)	Bulk density (g/cm^3)	Water absorption (%)	Open porosity (%)
0:2:10	1160	0,47	4,0	1,9
0:4:10	1230	0,50	14,0	7,0
0:6:10	1260	0,76	12,0	9,2
1:2:10	1130	0,57	2,4	1,4
	1140	0,59	2,7	1,6
	1150	0,59	2,4	1,4
1:4:10	1170	0,90	6,5	5,9
	1180	0,68	6,4	4,4
	1190	0,58	5,7	3,3
1:6:10	1230	0,71	11,5	8,2
	1240	0,56	10,5	5,8
	1250	0,54	9,2	4,9
2:2:10	1110	0,49	4,0	2,0
	1120	0,51	3,0	1,5
	1130	0,49	3,8	1,9
2:4:10	1120	0,64	6,3	4,0
	1130	0,53	5,7	3,0
	1140	0,46	3,0	1,4
2:6:10	1170	1,09	5,5	6,0
	1180	1,01	5,5	5,6
	1190	0,70	5,6	3,9

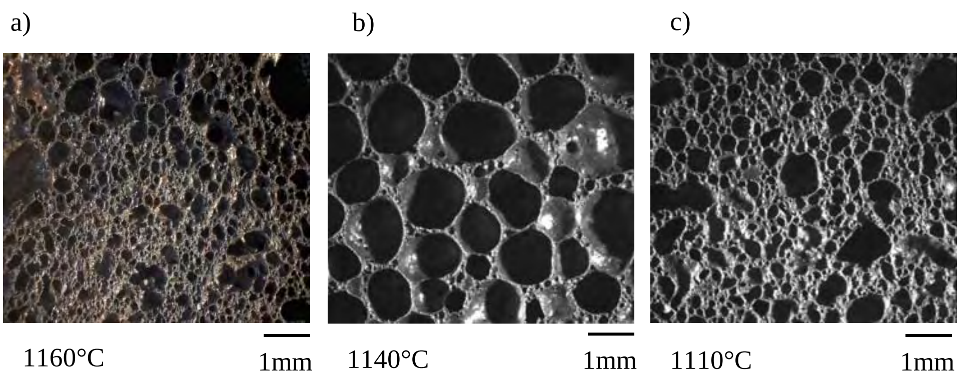

Figure 1. Pore structure of aggregates sintered at different temperatures:
a) Composition 0:2:10 sintered at 1160°C
b) Composition 1:2:10 sintered at 1140°C
c) Composition 2:2:10 sintered at 1110°C

It is clear that in the same temperature and the same NMP and clay content in the composition the lowest density is for the aggregate where the waste glass amount is higher.
Waste glass reacts as a fluxing agent and melts earlier and makes the aggregate structure softer allowing the gases to expand and develop a larger pore structure.
The surface properties of the aggregates are important for water absorption and open porosity. The results show a trend that the added glass waste lowers the water absorption and open porosity. Additional glass creates a compact and homogenous outer glassy film that makes them impervious to water. It is seen that the lowest open porosity 1,4-1,6% and water absorption 2,4-2,7% is for the composition 1:2:10 (glass waste:NMP:clay).
It is clear that the pore structure and surface properties of the aggregates are significantly affected by NMP.
The pore structures and surface textures of some aggregates composition of 2 mass ratio of NMP addition are illustrated in Fig. 1. It is seen that the sintering temperature decreases for 50°C compared to the reference composition 0:2:10 sintered at 1160°C and the 2:2:10 sintered at 1110°C.
Both compositions have a similar bulk density 0,47 and 0,49 g/cm^3, respectively, water absorption 4% and open porosity 1,9 and 2,0%, respectively.
The data in Table 1 show that for 2:2:10 in sintering range from 1110°C to 1130°C, the physical properties are similar; bulk density from 0,49 to 0,51 g/cm^3, water absorption from 3,8 to 4,0% and open porosity from 1,5 to 2,0%. For 1:2:10 composition the sintering temperature in the range from 1130 to 1150°C seems to be too high, because there are melting signs, which result in large pore structure and increased bulk density (0,57 to 0,59 g/cm^3).
The pore structures and surface textures of some aggregates composition of 4 mass ratio of NMP addition are illustrated in Fig. 2. The more NMP in the composition, the higher the sintering temperature is (Bajare et al., 2010). These structure photos present a slight increase in the pore size and a decrease in the sintering temperature, bulk density, water absorption and open porosity. The decrease in the sintering temperature compared to 0:4:10 and 2:4:10 compositions is 90°C and the decrease for the bulk density is from 0,5 to 0,46 g/cm^3.

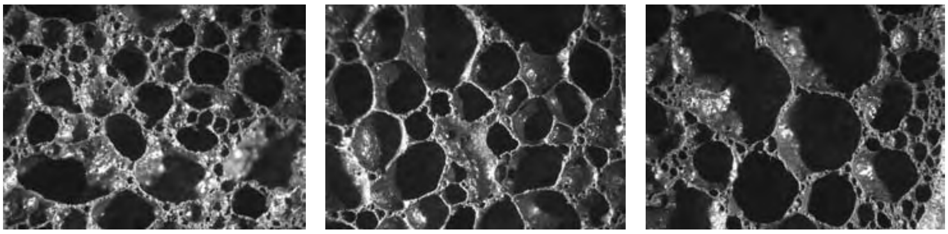

Figure 2. Pore structure of aggregates sintered at different temperatures
a) Composition 0:4:10 sintered at 1230°C
b) Composition 1:4:10 sintered at 1190°C
c) Composition 2:4:10 sintered at 1140°C

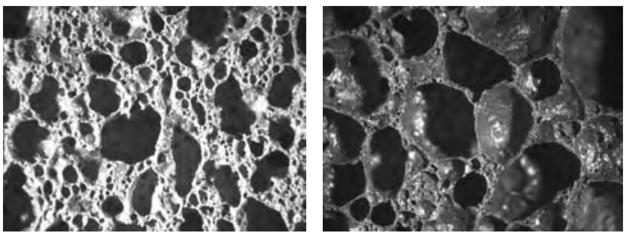

Figure 3. Pore structure of aggregates sintered at different temperatures
a) Composition 0:6:10 sintered at 1260°C
b) Composition 2:6:10 sintered at 1190°C

From the data in Table 1 it can be seen that for 1:4:10 sintered at 1180°C and 2:4:10 sintered at 1120°C the physical properties are similar; the bulk density from 0,64 to 0,68 g/cm^3, water absorption from 6,3 to 6,4% and open porosity from 4,0 to 4,4%, resulting in 60°C decrease in the sintering temperature. A similar situation is for compositions 1:4:10 sintered at 1190°C and 2:4:10 sintered at 1130, resulting also in 60°C decrease.

The pore structures and surface textures of some aggregates composition of 6 mass ratio of NMP addition are illustrated in Fig. 3. 0:6:10 and 2:6:10 compositions have a similar bulk density of 0,76 and 0,70g/cm^3, but a different pore structure with more voids. That might be explained by higher density of NMP than clay. The values of water absorption and open porosity decreased from 12 to 5,6% and 9,2 to 3,9%, respectively.

CONCLUSIONS

It was feasible to produce ECA from clay, NMP and waste glass with the characterized properties. Waste glass acted as a fluxing agent and lowered the sintering temperature, consuming a smaller amount of energy in the production process. The sintering temperature of ECA can be lowered for up to 60°C remaining the same pore structure and physical properties.

With increasing the sintering temperature the material is more effectively sintered but with a bubbled microstructure containing larger voids.

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