Materials Chemistry and Physics 205 (2018) 436–441

Contents lists available at ScienceDirect

Materials Chemistry and Physics

journal homepage: www.elsevier.com/locate/matchemphys

Recycling of electric arc furnace dust into glass-ceramic

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HIGHLIGHTS

- Toxic elements in dust were stabilized by transforming dust in to glass-ceramic.
- Solubility of toxic elements was extremely decreased by glass-ceramic production.
- Crystallization temperature was decreases by increasing of the dust content.
- Due to soft crystal phases, glass-ceramic have less hardness than initial glass.
- Crystal phases content were enhanced by increasing of dust amount in initial glass.

ARTICLE INFO

Article history:
Received 11 September 2017
Received in revised form
14 November 2017
Accepted 20 November 2017
Available online 24 November 2017

Keywords:
Casting
Stabilization
XRD
SEM
Glass-ceramics

ABSTRACT

Electric arc furnace dust was vitrified by SiO_2, $NaCO_3$ and CaO. The glass-ceramic produced from steel making dust was investigated in three aspects; stability of compounds, microscopic structure and mechanical properties. Leaching tests on electric arc furnace dust showed that the amount of Zn and Cd exceeded the environmental regulatory levels and the tests on glass ceramics exhibited that these products were chemically so stable. X-ray diffraction studies on them indicated that dominant phase in most samples was wollastonite. Scanning electron microscopy images of glass-ceramics corroborated that general shapes of crystalline phases were dendritic. By applying heat treatment, hardness of the product was significantly reduced and their mechanical strength was extremely increased. It showed that produced glasses had an average of 800 Vickers microhardness (HV) and after transformation to glass-ceramic by applying heat treatment, it was reduced to 500 HV.

1. Introduction

Various wastages are obtained in the form of slag, sludge and dust at different stages of steel production complexes. Some of them include considerable heavy metals that their releases may result in some environmental problems. Components of these wastages like Zn, Cd and Hg elements are very harmful from the point of pollution [1–4].

Steel manufacturing process produces lots of dust. Electric arc furnace dust (EAF) is one of the solid wastes produced by steel-making plant. This dust is produced during the melting of scrap in the furnace, and is collected in bag-houses. Composition of the EAF dust varies considerably depending on its source.

Considering the fact that steel manufacturing is done in the range of 1600 °C, all of Zn, Pb and Cd elements go into gas phase. In addition, small amounts of iron and alloying elements (Cr, Ni and Mn) also vaporize. The results of Toxic Characterization Leaching Procedure experiments on produced dust in steel manufacturing process show that amounts of toxic elements like Zn, Pb and Mn in dust are more than the permissible limit. So, electric arc furnace dust could not be put in the ground as usual without elimination of heavy metals [2–5].

In many cases, toxic elements and other useful elements of steel manufacturing dust were recovered and used considerably by doing metallurgical and chemical process. Hydrometallurgical processes are being developed to leach zinc from galvanized steel scrap prior to remelting, and both alkaline and acid leaching technologies are being evaluated to eliminate zinc from electric arc furnace dusts prior to their recycle [5]. In some cases, percentage of these elements in dust was so little that their recovery would not have any economic value so it could be landfilled. It should be considered that presence of this little amount of elements and compounds

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https://doi.org/10.1016/j.matchemphys.2017.11.045
0254-0584/

could extremely pollute environment [2]. Many industrial countries had imposed limitations for landfilling steel manufacturing dust: storing wastages in special places, preventing ground water from penetrating in landfilling places of dust and periodic ally controlling it are the samples of actions that were done to deal with environmental dangers of these toxic elements [3–8].

Glass-making by steel manufacturing wastages is one of the suitable ways for stabilization of toxic elements. In fact, by producing glass out of these wastages, toxic elements were stabilized in glass lattice and this seems to be an acceptable environmental method for stabilizing these elements [8–12].

Beside the glasses, glass-ceramics are more valuable products and have a higher rank compared to glass from the point of view of mechanical properties and chemical stability. With the heat treatment on initial glass, crystal delicate phases were formed in it which lead the glass ceramic to increase its strength. Glass-ceramics are poly-crystal materials and are formed when put under controlled heat treatment. Volumetric crystallization process is usually accomplished by double-stage heat treatments. The aim is to transfer the glass into microcrystal glass-ceramic with better properties than normal glasses that have especially high strength [13–17]. Practically, glass-ceramic can be used as floor glazed tiles and buildings with high abrasive resistance, containers for melting metals and salts, mill discs, nozzles resistant to corrosion and stabilizers of radioactive wastages [6–9].

2. Materials and method

Electric arc furnace dust was mixed with CaO, $NaCO_3$ and silica sand (SiO_2) with each one in a specific proportion. This proportion was selected in regard to CaO-MgO-SiO_2 triple diagram as the mixture, after melting, it was put in range of glass formation. Prepared mixtures were heated in SiC crucible to the temperature of about 1300 °C to be melted completely. The reason of using a SiC crucible in this research was related to elimination of the corrosion effects of crucible at high temperature and to decrease error percentage in experiments. The significant point in the casting melt was rapid solidification of melt and the creation of high thermal shock resulting in cracking and breaking the produced glasses.

To remove the intense thermal shocks, after casting, melt was immediately transferred to a furnace at 500 °C and after holding an hour at this temperature it got cold slowly to room temperature in the same furnace.

Heat treatments of produced glasses were done in two methods: single-stage and double-stage. To remove high thermal stresses, before heat treatments, glass samples were put in to a furnace at 500 °C for 15 min then they were heated to 950 °C for an hour. After this stage, samples were transferred to a furnace at 500 °C for the second time and remained at this temperature for 15 min for the elimination of high thermal stresses and at the end of heat treatments, samples got also cold slowly in a furnace to room temperature. In the double-stage heat treatment, at first, In order to minimize the destructive effects of thermal stresses on glass structure, samples were preheated at 500 °C and then they were put in to a furnace at temperature below the crystallization temperature to allow proper nucleation. In this paper, nucleation temperature was considered to be 200 °C lower than crystallization temperature.

In this study, in the double-stage heat treatment, the nucleation and growth temperature are distinct and they are obtained from DTA curve and according to glass transfer (Tg) and crystal growth (Tn) temperature. In this research, at first, samples were put in to a furnace at proper nucleation temperature for an hour. By considering of Tg and enough energy for nucleation of secondary phases in glass field, The initial temperature was 750 °C. In the second stage of heat treatment, the samples were transferred immediately to a furnace with 950 °C for 1 h to allow the crystallization of the all samples to be complete. At the end of double-stage heat treatment, in order to elimination of thermal stresses, the samples were transferred to a furnace with 500 °C for 15 min and after that, the samples were cooled slowly to room temperature.

DTA analysis was used for measuring the temperature of glass transfer and of crystal growth. Analysis was done by “Linseis L81/1750” set.

Structure and morphology of glass products and heat treated one were investigated by scanning electron microscope, “Philips XL30” model. Elemental analysis of produced glass-ceramic was done by Energy dispersive x-ray spectroscopy set, “SERON TECHNOLOGY” model, “AIS 2300C” series. Formed phases were examined by X-ray diffraction analysis set, “X'PERT-MPD″ model. Used voltage (V) and intensity of current (I) were 40 KV and 30 mA, respectively and in all experiments, CuKα single-wave ray was used by wavelength 1.54 A. Microhardness of initial glass and glass ceramic samples had been done by 5101 Micromet. Initial adjustments of microhardness measurement set for durometer test had been like this:

Initial load = 1 N, duration of loading = 10 s

3. Results and discussion

3.1. Chemical compound of electric arc furnace dust

The dust which is used in this study had been provided from Isfahan Mobarakeh Steel Complex, Saba unit, and approximate compound of minerals in it by X-ray fluorescence analysis has been presented in Table 1.

XRD diffraction model of the dust which is used in this study, has been shown in Fig. 1 As shown in dust diffraction model, the most important compounds of dust were $ZnFe_2O_4$ and Mn_3O_4, respectively.

3.2. Glass-making process

Fig. 2 shows glass formation range in CaO-MgO-SiO_2 triple diagram. In regard to the diagram, melting point of glass was about 1450 °C that fluxing compounds like $NaCO_3$ could be used to decrease the melting point [18].

On this base, four mixtures were prepared: G20, G25, G30 and G35 that G is an abbreviation of Glass and each numbers show percentage of used dust in prepared mixture. Table 2 depicts percentage of initial materials in initial mixtures. Maximum usage of dust in initial mixtures was in G35 sample. Due to facing the casting problems and high viscosity of melt with percentages upper than 35% (35% <), the experiments had been only done up to 35% of dust.

3.3. Heat treatments of glass samples

The results of differential thermal analysis have been given in Fig. 3. Curve (a) shows a thermograph of a glass sample with initial dust percentage as 20% and curve (b) is related to a thermograph of a glass sample with initial dust percentage as 30%.

Obtained results from DTA experiments have been presented in Table 3. Based on these results, the increasing of dust in an initial glass resulted in the decrease of T_c (temperature of crystallization) while almost The T_g (glass transition temperature) remained unchanged. The reason for this could be related to preparation of nucleation conditions of crystal phases with increasing of initial