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The use of cullet in the manufacture of vitrified clay pipes

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HIGHLIGHTS

- Glass cullet was incorporated in vitrified sewer pipes as feldspar substitution.
- We found that adding glass helps improving mechanical properties in some samples.
- Adding 10% glass reduces firing temperature by 200 °C.
- Low firing temperature reduces energy consumption and CO_2 emissions.

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ABSTRACT

Vitrified clay sewer pipes are used for sanitary drainage for their corrosion and abrasion resistance. They are manufactured by mixing clay, grog and feldspar as fluxing agent. Ground glass waste (cullet) was added to clay and grog mixture to substitute expensive feldspar. Samples with different percent glass addition were fired for 3 h at 1050, 1150 and 1250 °C. Porosity, bulk density, water absorption and modulus of rupture values were recorded for each sample. The micro-structural morphology of some samples was observed under Scanning Electron Microscope (SEM). The micrographs showed the presence of liquid phase and reduced porosity on cullet addition. It was found that 10% glass addition to samples yielded samples that meet standard requirements when fired at 1050 °C for 3 h corresponding to a reduction of about 200 °C in firing temperature. This in turns leads to savings in fuel and reduction in CO_2 emissions.

1. Introduction

The demands of municipal and industrial sewer application require a tough pipe that shows chemical and mechanical resistance. Several materials can be to manufacture sewer pipes like cast iron, concrete, plastic and vitrified sewer pipes [1,2]. Vitrified clay sewer pipes exhibit high abrasion, corrosion, heat and chemical resistance. They are manufactured by blending crushed clays, grog and feldspar, forming the blend into pipe shape, drying then firing to temperatures above 1200 °C to give the pipes a glassy finish.

Clay and grog form the main ingredients of a sewer pipe mix. Clay gives the main body of the product and ensures enough plasticity for the body to be shaped. Grog consists of non-plastic metakaolinite upon firing clays above 800 °C. It also reduces drying and firing shrinkages [3].

Feldspars represent a common fluxing agent used in ceramic industries. These are primarily used in industrial applications due to their alumina and alkali content. They usually contain potassium and sodium as minor elements beside their SiO_2 and Al_2O_3 content [4]. The alkalis in feldspar lower the melting temperature of the mixture. Upon melting fluxes form a glassy liquid that help in bonding different components of the mixture. Many studies were carried to investigate the effect of total feldspar substitution using industrial wastes of fluxing nature. Cement dust was used to produce vitrified sewer pipes [5] and partial substitution of feldspar by treated glass powder was used to produce ceramic bodies [6].

Glass cullet from waste bottles and windows is considered a non-hazardous waste [7]. In this respect, the problem of generated wastes becomes more significant since the rate of generation of solid residues is greater than their reutilization. The recovery and safe uses of glass cullet have been researched extensively in many useful applications. Many studies attempted to use waste glass in concrete as aggregate replacement although these attempts were unsuccessful when full replacement was tried [8]. On the other hand, acceptable results were obtained upon partial replacement

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of cement [9–11] or on using a hybrid combination of glass powder and nano-clay particles [12].

Glass cullet can also be used to prepare glass–ceramics materials through controlled crystallization of the glass phase [13] or by mixing it with another additive to the clay mixture such as incinerated recycled paper [14] or paper mill sludge [7,15,16].

Glass cullet was added to ceramic mixes as partial or total substitute of fluxes. Abadir et al. used glass cullet to replace feldspar in ceramic tiles [17] while it was used in a similar way in the production of sanitary ware [18]. Ground cullet powder was also used in the production of floor and wall ceramic tiles [19], building bricks [20], and porous ceramics (bricks) [21].

Complete replacement of feldspar by glass was successful in many cases. Using crystallizing glasses increased the strength of resulting porcelain [22], while recycled glass was used as very effective fluxing agent to produce an innovative stoneware ceramics, sintered at low temperature (below 1000 °C) [23,24].

The present work aims at investigating the effect of total substitution of expensive feldspar by glass cullet in the vitrified clay sewer pipes. The glass cullet was added in different percentage to obtain the optimum mixture that yields a sound vitrified clay sewer pipe satisfying the norms established by both Egyptian and British Standards under mild firing conditions.

2. Materials and methods

2.1. Assessment of raw materials

The raw materials used mainly consist of three portions: clay, grog, and ground glass waste (cullet). The basic mixture, suitable for producing vitrified clay pipe from Egyptian raw materials, was prepared. It consisted of about 85% ball clay from Aswan (upper Egypt), and 15% grog (defective and broken vitrified clay sewer pipes) which was used as a non plastic addition.

Both raw materials and glass waste were analyzed by X-ray fluorescence (XRF) using AXIOS, Panalytical 2005, Wavelength Dispersive (WD-XRF) Sequential Spectrometer for chemical composition. The mineralogical composition of these materials was determined by powder X-ray diffraction (BRUKUR D_8 ADVANCE COMPUTERIZED X-Ray Diffractometer), using a mono-chromatized Cu Kα radiation.

The as-received samples of raw materials were crushed using a laboratory hammer crusher to reduce their size in order to obtain smaller particle size that can be easily ground in a laboratory ball mill. Screen analysis was carried on for ground raw materials using sieve analysis according to ASTM standards [25].

The true density of raw materials was measured using the standard pycnometer method (density flask) [26]. Their bulk density was also measured.

2.2. Suggested mixtures

Clay was mixed with grog in a ratio of 85:15 and surplus ground cullet was added. In the present paper, the percent glass added was determined on a glass free basis: [glass × 100/(clay + grog)]. The clay–grog powder was mixed with different percentages of water and ground glass. The suitable water percent was chosen according to the workability and plasticity of pastes as determined by the Pfefferkorn method.

Rectangular samples of dimensions (110 × 30 × 25) mm^3 were molded with different percentage glass using a fixed water content of 25% (on dry basis). This water content provided the best workability of mixtures. Each sample consisted of 3 specimens. The formed samples were dried at (110 ± 5) °C overnight.

The green (unfired) samples were examined. Linear drying shrinkage (LDS) was evaluated along the longest sample dimension according to ASTM C 326/2009 [27]. Also, modulus of rupture (MOR) of unfired samples was evaluated by 3-point bending [28,29].

Green samples were fired in an electric furnace at three different temperatures 1050, 1150 and 1250 °C for 3 h soaking time.

2.3. Measurements and investigations

The fired samples were examined in conformity with both European and Harmonized Egyptian Standards of vitrified clay pipe [30,31]. Apparent porosity, water absorption, and bulk density, were measured according to both European and Harmonized Egyptian Standards of test methods for vitrified clay pipe [28,29].

In order to examine the produced samples based on their mechanical properties, the strength of fired samples and their modulus of rupture (MOR) were evaluated by three point bending test, (span = 80 mm, breadth = 30 mm, and thickness = 25 mm). The results were taken as average values between three specimens per sample.

The microstructure of fired samples assessed using a Scanning Electron Microscope apparatus (SEM) type JEOL-JSM 6510 with zoom magnification power up to 300,000. Its operating modes are either high-vacuum mode (for conductive specimens), or low-vacuum mode (for non conductive specimens without coating). This last mode was used in investigating the samples of this work.

3. Results and discussion

3.1. Assessment of raw materials

3.1.1. Chemical analysis

The chemical analysis of all raw materials was performed using X-ray Fluorescence (XRF) using AXIOS Panalytical 2005. Table 1 shows the average chemical composition of used raw materials in terms of the percentage of the oxides as obtained from XRF analysis.

The ground glass used in this study was of commercial grade using regular glass cups. The raw materials of soda glass are limestone, quartz and soda ash; we expect the XRF analysis to consist mainly of CaO, Na_2O, and SiO_2. This is effectively the result obtained as can be seen from Table 1. These oxides amount to about 94% of the glass composition.

The clay used mainly contains SiO_2, Al_2O_3, and Fe_2O_3. The relatively large amount of iron oxide showed through its reddish color.

3.1.2. Mineralogical analysis

The crystalline phases of the clay used were disclosed by XRD. Fig. 1 illustrates the XRD pattern. It shows that it consists mainly of kaolinite, illite, hematite, anatase, and quartz. The strongest peaks relate to quartz and kaolinite. As previous work has shown, XRD for grog showed that it to consist of mullite and quartz [5].

3.1.3. Sieve analysis

The particle size distribution (PSD) curves of ground clay, grog, and glass are displayed in Fig. 2.

The numerical mean particle size was calculated for each raw material, these mean particle sizes were 0.296 mm for clay, 0.504 mm for grog, and 0.104 mm for ground glass. The results reveal that on the average grog represents the coarsest fraction. This is expected in view of the difficulty of grinding hard grog compared to the much softer clay and glass.

3.1.4. True density and bulk density

Each raw material was tested to get its true and bulk densities. The values are reported in Table 2.

3.2. Assessment of green (unfired) bodies

3.2.1. Plasticity number

Fig. 3a shows the effect of percent glass addition on Pfefferkorn plasticity number. The water content corresponding to $H_0/H = 3.3$

Table 1
Average chemical composition of the raw materials used.

Constituents, wt.%	Glass	Clay	Grog
SiO_2	69.35	49.33	55.12
TiO_2	0.07	1.61	1.80
Al_2O_3	1.90	25.46	28.45
MnO	0.02	0.07	0.08
MgO	2.90	0.64	0.72
Fe_2O_3	1.36	8.95	10.00
CaO	10.16	0.74	0.83
Na_2O	13.70	0.29	0.32
K_2O	0.17	1.41	1.58
P_2O_5	0.02	0.17	0.19
SO_3	0.32	0.69	0.77
Cl	–	0.14	0.16
L.O.I	–	10.54	–
Total	99.97	100.04	100.00