Use of recycled glass as a raw material in the manufacture of Portland cement

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ABSTRACT

Scrap glass is a solid waste from daily recycling. Most of the waste glass is sodium-lime-silicate glass which has, more or less, similar chemical compositions to clay, a raw material in cement manufacturing. Therefore, we utilize the solid waste in cement raw mix by replacing part of the clayey component. In this study, the effects of the glass in cement raw mix on clinker burning were investigated. The experimental results show that the addition of the glass into cement raw mix (1) results in the formation of more liquid phase between 950°C to 1250°C compared with conventional raw meals; (2) decreases C₃S content in the clinker; and (3) increases NC₈A₃ content, which leads to flash setting and poor strength development of the cement. Therefore, it is necessary to increase the SG value \[ SG = \frac{SO_3 \times 100\%}{(1.292 K_2O + 0.85 Na_2O)} \] of the clinker when the glass is present in the raw mix.

1. INTRODUCTION

Currently, only a small fraction of the post-consumer glass is recycled directly to the primary market - the bottling and container industry. The problem is particularly serious in major metropolitan areas. The total amount of waste glass is projected to be doubled within about three years. The literature review has shown that there are many potential secondary uses of waste glass. The most important ones are asphalt, fiberglass, clean fill, and drainage.

Analysis indicates that most of waste glass from daily recycling is sodium-lime-silicate glass which has, more or less, similar chemical compositions to clay, a raw component in cement manufacturing. Therefore, it must be viable to use the waste glass in cement raw mix by replacing a small portion of the clayey component. However, our literature review shows that there has not been any attempt to re-utilize the waste glass in cement manufacturing. The most important factor that must be considered in the use of the glass as a raw material for the cement manufacturing is the alkali components in the glass, which result in an increase of alkalis, especially Na₂O, in the cement. It is well known that alkalis have various adverse effects on the production and applications of the cement. This may be the reason as to why the waste glass has not been used in cement production.

Compared with other recycling techniques, using the waste glass as one of the raw materials for making Portland cement has some advantages:

Le verre est l'un des grands déchets de la vie quotidienne. Une analyse des déchets de verre révèle que ceux-ci sont constitués essentiellement de silicate de soude et de calcium. Dans nos essais, des déchets de verre sont mélangés à la pâte de ciment en se substituant à sa composante argileuse, et l'effet de leur présence dans le ciment sur le brûlage dans le clinker a été examiné. Les essais montrent que l'adjonction de verre dans la pâte de ciment stimule la formation de la phase liquide entre 950°C et 1250°C par comparaison avec à sa forme habituelle, diminue le taux de C₃S dans le clinker et augmente celui de NC₈A₃ qui engendre une prise rapide et un faible développement de la résistance mécanique du ciment. Il faudrait augmenter de façon appropriée le SG \[ SG = \frac{SO_3 \times 100\%}{(1,292 K_2O + 0.85 Na_2O)} \] du clinker en présence de verre.
• No major investment is required, only some modifications on the current design of raw cement mix are needed;
• Due to the large amount of consumption of portland cement in the construction industry, the potential for the re-utilization of the waste glass is unlimited;
• All sizes of the crushed glass including very fine particles can be used as the raw mix for cement manufacturing since the raw materials must be grounded into fine particles for cement manufacturing anyway;
• The total energy for cement production will be reduced by the reduced amount of energy needed to burn off the water in the clay.

2. EFFECTS OF ALKALIS ON PROPERTIES OF PORTLAND CEMENT

Usually, about 50% of alkalis present in the raw feed in cement kilns are volatilized between 800°C and 1000°C [7]. The volatilized alkalis partially condense in the cooler parts of the kiln and return to the high temperature zone. The enrichment of alkalis in the kiln system leads to the formation of rings and a coating on the lining of the kiln and preheaters, thus causing shutdown of the system. A direct linear relationship between the density of the alkali-containing raw materials and the extent of volatilization has been observed [2, 11].

It appears that in the clinker SO3 makes the most of demand on the alkalis [5]. The alkali sulfates most commonly formed are: arcanite (K2SO4), aphthitalite (Na2SO4·3K2SO4), and calcium langbeinite (2CaSO4·K2SO4). It has been reported that the addition of gypsum in alkali containing raw materials has a positive effect on the formation of clinker minerals, and that the presence of alkali sulfates results in well developed alite and belite crystals [2]. It is also known from the literature that aluminates and ferrites accommodate about half or more of the available alkalis [6]. Free alkali reacts with C3A to form Na2O·8CaO·3Al2O3 (NC2A3) and free lime [9]. NC2A3, with its high reactivity, could cause setting problems to the cement [5]. Alkalis enter the structure of silicates to form KC23S12 and NC23S12, both are kinds of C2S stabilized by alkalis and hardly form further into C2S [3].

When alkali-containing cement is mixed with water, the alkali metal ions readily go into the liquid phase of the hydrating system and affect the rate of cement hydration. This, in turn, affects the strength and other engineering properties of the hardened cement paste. It was found that most of the alkali cations remained in the pore solution, only a small portion is incorporated in the solid hydration products [2]. The pH value of the pore solution in a high alkali cement paste may reach 12.9 within two minutes, and 13.7 or even higher after 28 days [4]. The presence of alkali ions depresses the solubility of Ca2+. The decreased solubility of Ca(OH)2 varies the rate of nucleation and crystallization of hydration products, and therefore alters the setting as well as hardening processes of the cement.

A high alkali level in Portland cement (e.g. over 0.8% Na2O) affects early strength of the cement paste, especially when the alkali presents as alkali sulfates in the cement. In this case, an increase by about 10% in early age strength is associated with a decrease by about 10-15% in 28 day strength [5].

According to the experience of the German cement industry, by controlling the SG value, which is expressed as: SG = 100%·SO3/(1.292 K2O + 0.85 Na2O), the cement with a high alkali content could attain normal properties. For the Na2O-riched clinker, the proper range of the SG value should be from 90% to 100%; for K2O-riched clinker, the range should be from 60% to 70% [1].

In addition to the effect of high alkali on the early strength development of concrete, there is another major adverse effect from using high alkali cements, that is, the damage due to the so-called alkali-aggregate reaction (AAR) in matured concrete, which is a long-term durability problem. AAR has been a research topic in the concrete industry for long time, and it will not be discussed here in detail.

From above review, it is clear that high alkalis in the raw mix may cause problems in cement manufacturing, and high alkalis in Portland cement may lead to various adverse effects on the properties of the cement and the concrete made of the cement. Therefore, a great caution must be taken when using the waste glass as one of the raw components. In the present study, we systematically investigated the methods that can be used to avoid the adverse effects of the glass on properties of cement as well as on the formation of cement clinker, and find the maximum rate to replace the clay by the waste glass without any major impact on the resulting Portland cement.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Preparation of cement clinkers

All of the raw materials used in the present study were from a local cement plant in Colorado. The results of chemical analysis for the raw materials are given in Table 1.

The raw materials were separately ground in a jar mill into powders of fineness below 75 μm. The raw materials were then mixed with or without the waste glass according to given formulas. Cement raw meals used in the present study have similar chemical compositions as those commonly used in the Portland cement plants.

The raw meals were then mixed with a small amount of water and pressed into tablets of 25.4 mm in diameter and 4 mm in height. After dried in an oven under 80°C, the tablets were put into a chamber furnace and burnt at different temperatures. After burnt for a half hour, the clinkers were taken out of the furnace and cooled down in the air.

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