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Cement and concrete production using white waste glass from recycled bottles

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ABSTRACT:
Most researchers focus on using waste glass as a partial replacement for fine aggregate in the cement matrix. This article proposes an alternative method of managing waste glass in the concrete industry, as an addition to concrete in the form of finely ground glass powder and as a component of the cement. Waste glass ground into a glass powder was dosed into concrete in quantities of 5 and 10% of the weight of cement while reducing the same amount of fine aggregate. Tests that were carried out on three concretes (including a control concrete) included compressive strength, water penetration depth and water absorption. Pre-shredded waste glass from white bottles was also ground together with previously burned Portland clinker. The glass was dosed in quantities of 6 and 12% of the weight of clinker. In this way, two types of cement were obtained: cement with the addition of waste glass and the control cement. Tests carried out included compressive strength after 2, 7, 14, 28 and 90 days, the beginning of cement setting time and its grinding degree. An analysis of the obtained test results confirmed the possibility of using waste glass in a way other than previously proposed. Concretes including fragmented glass from bottles have obtained satisfactory results of compressive strength, water absorption and penetration. Cements obtained as a ground mixture with waste glass were characterized by much better mechanical parameters compared to the control sample cement.

KEYWORDS:
glass recycling; concrete; cement; white glass

1. Introduction

For many years, research has been conducted on a large scale to manage waste, including post-production waste for the production of cement matrix materials. There are several known studies into using alternative aggregate originating from waste red, sanitary and decorative ceramics [1-7], bottle glass, car glass and cathode ray tubes etc. In these studies, the concrete cement matrices where the authors introduced waste glass were characterized by better mechanical and physical parameters, and significantly higher sulfate resistance [8-13].

The authors of this research focused mainly on the use of industrial waste as a recycled aggregate to replace the aggregate mix in concrete composites. Waste glass has a high silica content, on average about 70%, which may entitle it to be used as a partial substitute for cement in concrete or directly as a cement component. It is well known that glass in its composition has alkali (K_2O and Na_2O compounds), which in combination with reactive silica that may occur in aggregates, can lead to a harmful alkali-silica (ASR) reaction. The product of this reaction is an alkaline - silica gel formed in the cement matrix, which increases in volume under the influence of moisture. This leads to cracks on the border of coarse aggregate and cement leaven, and as a consequence, to the destruction of the concrete. In order for the harmful

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reaction to occur, the alkali-silica must contain reactive silica in the aggregate and the concrete composite must be exposed to moisture. In addition, many researchers have stated that the addition of glass to concrete in the form of finely ground powder does not necessarily cause the formation of an alkali-silica gel and can be successfully used in cement products [14-17]. The introduction of fragmented glass cullet and silica fly ash into concrete composites together with blast furnace slag, metakaolin or lithium compound significantly reduces the risk of ASR [18, 19]. The possibility of using glass cullet for the production of cement binder was confirmed by Chen et al. [20], who fired in a rotary kiln a Portland clinker together with glass cullet from bottles. The cement obtained in this way did not differ from the control cement, and no significant increase in alkali content was found. Mators and Sousa-Coutinho [14] used fragmented waste glass as a partial cement replacement for mortars. In the tested mortars, they replaced 10 and 20% of cement mass with fragmented glass powder. They found that mortars with a 10% addition of glass powder obtained a much higher sulfate resistance compared to the reference mortar. Mortars, with the addition of glass powder also obtained comparable compressive strength values with the control mortar. A slightly higher alkali content was found in mortars with the addition of fragmented waste glass, but the expansion of ASR was quickly reduced. Khmiri et al. [21] made 28 series of mortars, to which they used different contents of white and green waste glass. They showed that waste glass exhibits pozzolanic activity in the presence of cement, and the addition of 20% shredded glass with a diameter of up to 20 μm allows comparable compressive strength to be obtained with the reference mortar.

2. Research scope and research results

The literature review confirmed the possibility of using waste glass for the production of concrete composites and cement. Used glass from white bottles was prepared in two ways: as a cement component (by grinding with previously burned Portland clinker) and as a concrete component in the form of glass powder. By using a laboratory ball mill (Fig. 1), pre-shredded glass was co-milled with Portland clinker. The glass was dosed in quantities: 6% (C6 series cement) and 12% (C12 series cement) clinker mass in the control series (C series cement). Figure 2 shows the mill input: Portland clinker together with fragmented waste glass. The composition of the ball mill feeds is shown in Table 1.

Fig. 1. Laboratory ball mill

Fig. 2. Clinker and glass as a ball mill input

Table 1
Mass table for 5 kg charges in a ball mill

Cement series	Mass proportions		
	Clinker + fragmented waste glass (95% of the charge mass) [kg]		Anhydrite (5% of the charge mass) [kg]
C	0	4.75	0.25
C6	0.285	4.465	0.25
C12	0.57	4.18	0.25

All the series of cement were obtained by grinding for 45 minutes in a laboratory ball mill. The following tests were performed for the obtained cements: compressive strength of standard mortars according to PN-EN196-1 [22], beginning of setting time according to PN-EN196-3 [23], fineness by means of Blaine air permeability method according to PN-EN196-6 [24]. Compressive strength tests were carried out after 2, 7, 14, 28 and 90 days of maturing of standard mortars. The compressive strength test was carried out for six samples. Test of setting time and grinding degree were made for three samples. The average values are presented in Tables 2 and 3.

Table 2
Results of the compression strength testing of the obtained cements

Cement series	Mean compressive strength R_c determined after days [MPa]				
	2	7	14	28	90
C	21.3	35.0	40.4	47.5	54.0
C6	19.0	32.5	39.5	49.0	56.9
C12	19.1	33.7	39.0	48.8	57.4

Table 3
Test results of setting time and fineness examinations for the obtained cements

Cement series	Initial setting time [min]	Fineness [cm^2/g]
C	95	5090
C6	100	5020
C12	100	4995

Recycled glass was ground with ceramic meal in a disintegrator and was also added to concrete in the following quantities: 5% (K5 concrete series) and 10% cement weight (K10 concrete series) with simultaneous reduction of fine aggregate. CEMI 42.5R Portland cement, a natural aggregate mix and SikaCem Superplast superplasticizer were used for all concretes. The compositions of the concrete mixes are shown in Table 4. For all concrete mixes, a consistency test was performed using the slump test in accordance with PN-EN 12350-2 [25]. The following tests were carried out for concrete: compressive strength according to PN-EN 12390-3 [26], water penetration under pressure according to PN-EN 12390-8 [27] and water absorption according to PN-B/88-06250 [28]. The test results are presented in Table 5.

Table 4
Composition of concrete mixtures

Component content [kg/m^3]	Test concrete series		
	K - Control	K5	K10
Portland cement 42.5R	355	355	355
Water	149	149	149
Coarse aggregate	1229	1229	1229
Sand	691	673.25	655.5
Glass meal	–	17.75	35.5
Superplasticizer	3.55	3.55	3.55

Table 5
Test results for concrete composites

Test series	K	K5	K10
Slump test [mm]	45	45	40
Mean compressive strength f_{cm} [MPa]	62.2	64.3	65.8
Concrete class	C45/55	C50/60	C50/60
Depth of penetration of water [mm]	48	48	47
Water absorption [%]	4.2	4.0	4.0

3. Conclusions

Based on the laboratory tests carried out, the following conclusions are made:

- An innovative method consisting of grinding Portland clinker, previously burnt in a rotary kiln, with glass cullet gave very good results. The cements obtained in this way had better parameters compared to the control cement. Cements with the addition of cullet after 2, 7 and 14 days obtained slightly lower mean compressive strength compared to the control cement. However, after 28 and 90 days, cements with the addition of glass obtained higher mean compressive strength compared to the control cement. Cement with addition 6% glass obtained a higher strength by 3.16% after 28 days, and after 90 days a higher strength by 5.37%. Similarly, cement with the addition of 12% glass obtained higher strengths by 2.74 and 6.3%.
- Concrete made with the use of glass powder obtained very promising test results. The control concrete obtained a mean compressive strength of f_{cm} = 62.2 MPa. The concrete in which glass powder was 5% of cement mass obtained a mean compressive strength 3.38% higher compared to the reference concrete. The addition of 12% glass powder caused a 5.79% increase in strength compared to the reference concrete. Concrete with the addition of glass powder also obtained lower values of water absorption and depth of penetration.

– There is an alternative possibility to use glass cullet from white bottles in the cement and concrete industry. The use of glass cullet as a partial replacement for aggregate in concrete composites, which has been the subject of much research, is not the only possibility.

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[28] PN-88/B-06250. Beton zwykły.

Produkcja cementów i betonów z wykorzystaniem białego szkła odpadowego z recyklingu butelek

STRESZCZENIE:
Większość badaczy skupia się na wykorzystaniu szkła odpadowego jako częściowego zamiennika kruszywa drobnego do materiałów o matrycy cementowej. W pracy zaproponowano alternatywny sposób zagospodarowania szkła odpadowego w przemyśle betonowym, a mianowicie jako dodatek do betonów w postaci drobno zmielonej mączki szklanej oraz jako składnik cementów. Rozdrobnione do postaci mączki szklanej odpadowe szkło dozowano do betonów w ilościach 5 i 10% masy cementu, redukując równocześnie taką samą ilość kruszywa drobnego. Dla trzech betonów (w tym beton referencyjny) wykonano badania: wytrzymałości na ściskanie, głębokości penetracji wody oraz nasiąkliwości. Wstępnie rozdrobnione szkło odpadowe, pochodzące z białych butelek, wspólnie zmielono także z wcześniej wypalonym klinkierem portlandzkim. Szkło było dozowane w ilościach 6 i 12% masy klinkieru. Uzyskano w ten sposób dwa rodzaje cementów z dodatkiem szkła odpadowego oraz cement referencyjny, dla których wykonano badania: wytrzymałości na ściskanie po 2, 7, 14, 28 i 90 dniach, początku czasu wiązania cementu oraz jego stopnia zmielenia. Przeprowadzona analiza uzyskanych wyników badań potwierdziła możliwość innego zagospodarowania stłuczki szklanej niż dotychczas w większości proponowane. Betony z udziałem rozdrobnionego szkła z butelek uzyskały zadowalające wyniki wytrzymałości na ściskanie, nasiąkliwości oraz penetracji wodą. Cementy uzyskane ze wspólnego zmielenia ze szkłem odpadowym charakteryzowały się znacznie lepszymi parametrami mechanicznymi w porównaniu do cementu referencyjnego.

SŁOWA KLUCZOWE:
recykling szkła; beton; cement; szkło białe