Construction and Building Materials 146 (2017) 221–230

Contents lists available at ScienceDirect

Construction and Building Materials

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

Review

# Influence of mass concrete constituents on its properties

Maciej Batog [a,*], Zbigniew Giergiczny [a,b]

[a] Górażdże Cement S.A., ul. Cementowa 1, Chorula, 47-316 Górażdże, Poland
[b] Silesian University of Technology, Faculty of Civil Engineering, ul. Akademicka 5, 44-100 Gliwice, Poland

## HIGHLIGHTS

- Proper selection of concrete constituents help to minimize its temperature rise.
- Temperature rise depends on amount of binder and its type.
- Low clinker cements allow to significantly reduce hardening temperature of concrete.
- Increase of w/c-ratio above 0,5 reduces cement heat of hydration.
- Aggregate type has not affected concrete hardening temperature.

## ARTICLE INFO

*Article history:*
Received 13 January 2017
Received in revised form 6 April 2017
Accepted 10 April 2017

*Keywords:*
Fly ash
Ground granulated blast furnace slag
Mass concrete
Aggregate
Low heat cement

## ABSTRACT

Hereby paper presents the results of the research on determining the impact of cement and aggregate type on the formation of hardening temperature and mechanical properties of concrete. In the study, the six cement types, which contain up to 70% of main non-clinker constituents and four types of aggregate (basalt, granite, limestone and gravel) were used. The test results showed that cements with low clinker content allow to significantly reduce hardening temperature of concrete and thus, minimize the risk of cracks formation in concrete. Aggregate type has not affected concrete hardening temperature. However, it has an impact on magnitude of generated thermal stresses, caused by different thermal expansion coefficients of the aggregates. The most favourable aggregate types to use in mass concrete from the all analysed are granite, basalt and limestone. Usage of gravel aggregate in concrete, consisting mainly of quartz, might lead in certain unfavourable conditions to crack formation, caused by generated thermal stresses.

**Contents**

---

* Corresponding author.
*E-mail address:* maciej.batog@gorazdze.pl (M. Batog).

http://dx.doi.org/10.1016/j.conbuildmat.2017.04.085
0950-0618/

## 1. Introduction

Thermal effects associated with the hydration of cement are of particular importance in massive concrete structures. Caused as a result of the heat released by the hydration of cement, the temperature difference between the interior and relatively quickly cooled outer surface of the concrete element, leads to thermal stresses formation. In extreme conditions, this may result in cracks in the entire volume of the concrete element and thereby, its durability and service life reduction [1–3]. In order to minimize the effect of thermal stress on the durability of concrete structure, the number of technological processes such as cooling of concrete, stage concreting, proper selection of concrete constituents, etc. are applied.

One of the most effective method to reduce thermal stress is the “introduction” of cement with as low as possible amount of heat of hydration [4]. This can be achieved by applying in the concrete composition - cements with decreased amount of Portland clinker e.g. CEM II ÷ CEM V or VLH V/B (S-V) 22,5 [5–7], while keeping in mind, that the development of the mechanical properties of such concrete is slower in comparison to Portland cement CEM I [4,8–10]. Similar results are obtained, when mineral additives such as siliceous fly ash or ground granulated slag are used directly in concrete [11–17]. In the case of massive structures the rate of strength development is of secondary importance. The main objective is to ensure the durability of such a structure. Early strength should exceed the value of thermal stress and be high enough to allow further progress of planned construction works. Properly built and cured concrete, with cements containing high amount of mineral additives, will be also characterized by a high durability in designed service life [12–17]. There is also significant ecological effect related to the usage of cements with mineral additives, which is associated with lower $CO_2$ emissions due to the replacement of a part of Portland cement clinker by other major non-clinker constituents of cement. Both, proper selection of the aggregate and its grading curve also reduce the negative effects of the temperature increase during hardening of the massive concrete, however, optimizing cement content in the concrete mix is also relevant from the mass concrete point of view [1,17].

The aim of the study was to show that the appropriate selection of cement and aggregate type, as well as water-cement ratio in the concrete mix reduces the temperature gradient and the amount of stress during massive concrete hardening.

## 2. Test methods

The research program included in its scope: determination of cement mechanical and physical properties, cement heat of hydration, concrete compressive strength, development of the temperature in concrete, thermal conductivity and heat capacity of concrete.

Compressive strength of cement was determined according to EN 196-1 [18] after 2, 28 and 90 days. Water demand, setting time, soundness was determined acc. to EN 196-3 [19] and specific surface acc. to. EN 196-6 [20].

The chemical composition was determined by XRF method according to EN 196-2 [21]. Quantification of phases was performed by XRD method. For the XRD (Bruker D8 Advance) analysis, the cements were mixed with internal standard (10% of corundum). Rietveld refinements were performed using Topas 4 software from Bruker AXS.

Heat of hydration of cement was determined by isothermal calorimeter produced by TamAir TA Instruments. Tests were carried out for 72 h on cement pastes with water-cement ratio w/c = 0,4; 0,5 and 0,6 at 20 °C and 50 °C.

Compressive strength of concrete was determined on cubic samples 150 mm x 150 mm x 150 mm in accordance with the procedure presented in EN 12390-3 [22] after 1, 2, 7, 14, 28, 56 and 90 days of hardening. The samples after casting were stored according to the guidelines presented in the EN 12390-2 [23].

The development of concrete hardening temperature was measured on a cubic sample 400 mm × 400 mm × 400 mm, which was insulated by polystyrene plates with thickness of 150 mm and coefficient of thermal conductivity of 0,044 W/m K. Setup for the temperature measurement is shown in Fig. 1. For temperature measurements a multichannel electronic thermometer TES 1383 with K-type thermocouples was used. Temperature measurement was taken at three points: A – in the centre of the cube, B – in the middle of the side surface, and C – at the edge of the cube 20 cm above basis (Fig. 1). The maximum temperature difference between points A, B and C was 1 °C, due to that for further analysis values from point A were used. External temperature during the measurement was 20 °C ± 2 °C.

Thermal conductivity and heat capacity of concrete were determined using the Isomet 2104 device made by Applied Precision Inc. The measurement method is based on a transient heat transfer analysis, namely the temperature reaction of the test material to the thermal impulse. The heat flow is generated by the electric heater directly in contact with the test sample. Evaluation of conductivity and heat capacity of the sample is based on a periodic temperature measurements as a function of time. The apparatus allows the measurement of thermal conductivity in the range of 0,015 ÷ 6,0 W/mK, and heat capacity in the range of $4{,}0 \cdot 10^4 \div 4{,}0 \cdot 10^6$ J/(m = K). The tests were performed on a concrete cubic samples having a side length of 100 mm, dried to

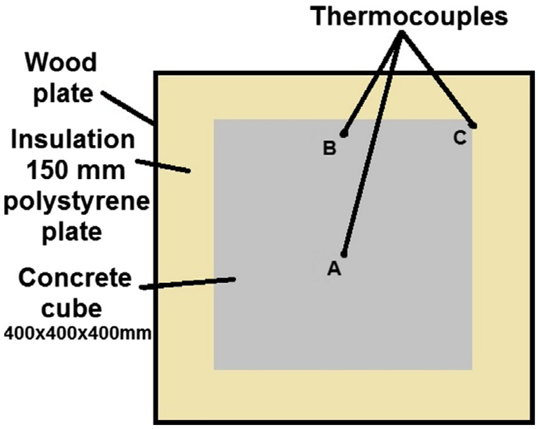

**Fig. 1.** Setup for concrete block temperature measurement (view from above).

**Table 1**
Content of non-clinker constituents in cement.

| Cement type | Non-clinker constituents content,% | | |
|---|---|---|---|
| | Ground granulated blast furnace slag | Siliceous fly ash | Minor additional constituents$^{1)}$ |
| CEM I 42,5R | - | - | 4,3 |
| CEM II/B-S 32,5R | 27,1 | - | 4,6 |
| CEM II/B-V 32,5R | - | 29,9 | 4,4 |
| CEM III/A 32,5N-LH/HSR/NA$^{2,3)}$ | 58,9 | - | - |
| CEM V/A (S-V) 32,5R-LH/HSR/NA$^{2,3)}$ | 18,2 | 19,6 | - |
| VLH V/B (S-V) 22,5 | 34,4 | 33,3 | - |

1) Limestone with 98,2% of $CaCO_3$ and TOC = 0,07%.
2) HSR – sulphate resistant cement acc. to Polish Standard PN-B-19707:2013.
3) NA – low alkaline cement acc. to Polish Standard PN-B-19707:2013.