



Massive concrete constructions - problems and tasks for a technologist

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ABSTRACT:

The article presents fundamental issues related to the construction of massive concrete structures. The specific nature of the dangers associated with concreting and aspects of binder selection for the concrete mix were described. Metallurgical cement has been characterized as a component of massive concrete constructions. It was pointed out that cements containing a high content of granulated blast furnace slag allow the mitigation of the risk of early thermal cracking in concrete, and gives the possibility of obtaining concrete with high durability. The use of metallurgical cements is also a pro-ecological activity that reduces the release of CO₂ emissions into the atmosphere.

KEYWORDS:

massive concrete constructions; heat of hydration; thermal stress; metallurgical cement

1. Introduction

The construction of massive concrete structures requires a specific approach and appropriate care when applying technological solutions already used in designing the composition of the concrete. Concreting of massive elements requires concrete specifications to take into account occurring risk factors. The most serious problem is the maturing of concrete by cement hydration, which is an exothermic process. Concrete used for massive elements should not only comply with the standard but must also minimize the risk of thermal scratches. Its composition should be selected so that the production of heat during hydration is as low as possible and is created at the slowest possible pace [1, 2]. The technologist is faced with the task of obtaining concrete with the required strength and durability while at the same time, selecting the appropriate binder system. The cement component that affects the hydration heat is clinker, and its production produces large amounts of carbon dioxide in the process. Action that can be taken to reduce the amount of CO₂ emitted is, among others, the use of low-emission components in cement. One such component is granulated blast furnace slag, which is a by-product of the production of pig iron in metallurgical furnaces. Blast furnace slag has latent hydraulic properties and, after crushing and activation, binds and hardens like Portland cement. Granulated blast furnace slag in the cement composition causes changes in the cement properties, and from the point of view of massive constructions it extends the setting time and reduces the heat of hydration [3]. Its presence in cement reduces the flow limit and also slightly increases the plastic viscosity [4]. The use of blast furnace slag as a substitute for clinker allows the use of a by-product formed during the production of pig iron, thus reducing the consumption of natural raw materials, energy and CO₂ emissions to the atmosphere during cement production thus subscribing to the strategy of sustainable development.

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2. Massive constructions

2.1. Assessment of the massiveness of structures

Wherever high rigidity in buildings is required or where vibrations from machinery occur, monolithic constructions are used. Their use is widespread in the form of block or slab foundations, foundations and abutments of bridges, dams, etc. When considering massive concrete structures, guidelines can be found relating to industry standard BN-62/6738-07 [5]. The division of hydrotechnical concretes according to the standard, depending on the dimensions, indicates that massive elements are those whose smallest dimension is at least 150 cm. In the American Standard ACI 116R [6], the concept of massiveness is more general. Massive concrete has been defined as “any volume of concrete large enough to require action to reduce the risk of scratches due to volume changes during the heat generated by cement hydration.” More favorable criteria for massive concrete constructions can be found in [1]. Massiveness assessment can be made on the structure geometry based on the mass coefficient of the structure m_k

$$m_k = \frac{S}{V} \quad (1)$$

where: S - area of the element [m^2], V - volume of the element [m^3].
The obtained m_k value allows classification of the structure (Table 1).

Table 1
Ranges of massiveness of construction

Massiveness	The massive factor of the structure m_k [m^{-1}]	Replacement thickness e_m [m]
massive	≤ 2	≥ 1.0
medium massive	$2 \div 15$	$0.15 \div 1.0$
not massive	≥ 15	≤ 0.15

Another measurement considered in the assessment of dangers caused by the increased temperature of concrete is the apparent mass coefficient m_p , and the equivalent thickness e , which take into account, in addition to the geometry of the structure, it's cooling [1]. It is particularly useful for the cooling of only a fragment of the surface of the structure:

- apparent massiveness coefficient

$$m_p = \frac{S_p}{V} \quad (2)$$

- substitute thickness

$$e = \frac{V}{S_p} \quad (3)$$

where: S_p - surface cooled by ambient air [m^2], V - volume of the element [m^3];

- replacement thickness for the prismatic elements:

$$e = \frac{2F}{U_z} \quad (4)$$

where: F - cross-sectional area [m^2], U_z - the length of the perimeter of the cross-section, through which the surface is cooled by the ambient air [m].

The specific nature of massive concrete elements results from the large cross-section of structures used and that technology must minimize temperature increases. Phenomena occurring inside the concrete during its hardening are associated with the processes [7]:

- heat conduction due to temperature gradient,
- moisture flow due to concentration gradient,
- moisture flow due to temperature gradient,
- heat flow due to concentration gradient.

The temperature value and its distribution are affected by [8]:

- type and amount of cement,
- aggregate type,
- the dimensions and shape of the element,
- environmental conditions,
- work conditions (initial temperature, use of thermal insulation, use of internal cooling).

Thermal stresses are the dominant stresses in massive structures and they get bigger, the larger the temperature increase inside the concrete. Exceeding the resulting thermal stress by the tensile strength of concrete is a common cause of structural scratches.

2.2. Technological factors preventing the loss of monolithicity

In order to minimize the temperature rise caused by the heat of hydration, the technology used in constructing massive structures requires a comprehensive approach at every stage of manufacture. Technological factors preventing excessive heating of the structure can be divided into three groups [1]: factors available during the execution of the concrete mix, factors available during concreting, factors available at the care stage.

At the stage of making the concrete mix, technological ingredients include the composition of the mix and its initial temperature. The factors available during concreting include those that depend on the technologist and those that are associated with activities performed on the construction site. The most important factor in this group is the choice of the concreting system, as well as the thermal preparation of the substrate, the schedule and the concreting rate. The most favorable concreting conditions are low air temperatures (positive), i.e. concreting in summer should be avoided and it is best to carry out work after dark.

At the concrete care stage, the thermal care method should be chosen: surface cooling, internal cooling, thermal insulation. The development of a comprehensive project for massive construction technology should include the following aspects [1]: computer simulation, concreting technology, care methods, monitoring of the structure.

Most interesting from an engineering point of view is the possibility of creating a computer simulation of the concrete's behavior. It allows the confirmation of the correct choice of material and, with assumed input data (all factors that can be influenced) allows the planning of the entire concreting process, as well as subsequent care. Control of the concrete maturation process in massive structural elements allows the monitoring of emerging temperature gradients. Temperature control gives an indirect answer that the allowable stresses have not been exceeded and the structure has retained its monolithicity.

2.3. Blast furnace slag as a cement component for massive concretes

The selection of the binder is the most important factor when regarding massive structures. The criteria for the selection of the binder must take into account both the required properties shaping the durability of the concrete, taking into account the conditions of operation of the object, as well as special properties in the form of heat of hydration. The type of cement used for the production of concrete in accordance with PN EN 206 [9] is an essential factor affecting the amount and rate of the heat of hydration. The rate of heat release depends on the mineralogical composition of the cement, its specific surface (fragmentation), the value of the water-cement ratio of the concrete and the amount of hydraulic and pozzolanic additives. From the standpoint of normalization, cements were divided into two groups:

- common cements covered by the standard PN-EN 197-1:2012 [10],
- special cements covered by standards PN-B-19707:2013-10 [11] and PN-EN 14216:2015-09 [12].

Among the large group of cements available, special cements with low LH heat content are commonly used. Any common cement can be considered as a cement with low hydration heat, provided that the heat of hydration is not more than 270 J/g (Table 2).

Heat in massive constructions should be emitted in the maximum possible period of time. This treatment can be achieved by using cements with low heat of hydration LH from types of metallurgical cements CEM III or multi-component cements CEM V.

Cements containing granulated blast furnace slag are very popular in the case of massive structures, and due to the increased resistance to chemical aggression, they are the material for the construction of hydrotechnical structures and walls of sewage treatment plants. Blast furnace slag in the cement composition increases the setting time, reduces the heat of hydration, improves workability and preserves consistency over time.

3. Examples of implementation of massive objects

3.1. Foundation slab in Bełchatów Power Plant

In Bełchatów, in 2007, the concreting of the foundation slab took place, the volume of which was over 27 000 m³, and the entire concreting process was carried out without technological breaks [13]. The foundation slab had a rectangular projection with an area of over 8200 m² and its thickness ranged from 2.5 to 4.5 m (Fig. 1) [14]. It was a complex task that required careful preparation of the technological design project and organization of the work, the development of which was started six months before the site work was carried out. At the stage of composition development, it was necessary to ensure that the concrete mix met the design assumptions and required a unique approach to obtaining the minimum temperatures and temperature gradients in the concrete slab resulting from the cement hydration process.

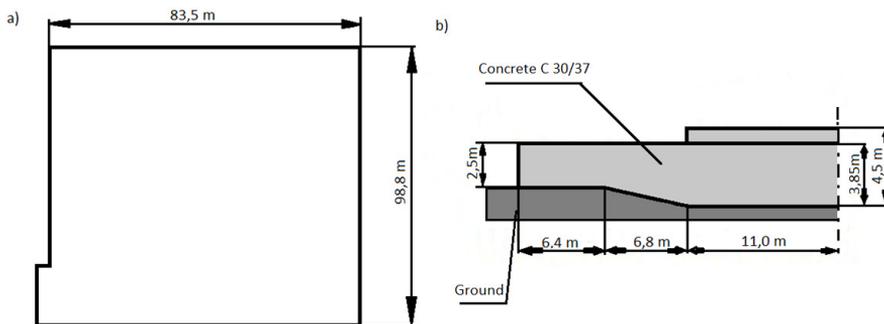


Fig. 1. The foundation slab: a) view b) cross-section

Metallurgical cement CEM III/A 32.5 N NA HSR LH from the Rudniki Cement Plant was used to make the concrete, which has a low hardening heat. An admixture delaying the setting time and a superplasticizer were used, which allowed, with a low W/C ratio, to achieve the assumed consistency of the mix and low heat of hydration, as well as a slow temperature increase in the initial stages of binding.

To make the slab, a total of approximately 6800 tons of cement, 3400 tons of fly ash, 51 400 tons of aggregate, 180 tons of concrete admixtures [15] were needed, and appropriate logistic solutions had to be adopted to ensure such a large amount of concrete components of the same quality could be acquired.

Another equally important task was to gather the right amount of equipment for the production of the concrete, its transport and laying, and to prepare additional equipment in the event of a failure. The project involved obtaining a laying capacity of 200 m³ per hour, with diagonal layers using 6 pumps [15]. The mix was produced in two mobile factories and two stationary factories near the construction site.

Concrete care and temperature monitoring were provided to ensure monolithicity. The assumed concrete care consisted of spraying a water mist, and two layers of bubble wrap provided thermal insulation. Thermal care was to be carried out 24 hours after the concrete was formed and moisture care was carried out by periodic spraying with water. Continuous temperature monitoring for 33 days in the foundation slab showed a maximum temperature of 52.0°C after 252 h from the beginning of concreting. The maximum temperature gradient was recorded after 180 hours and it was 22.2°C/1 m. Due to night temperature drops, monitoring showed the need for additional insulation of the slab with another layer of bubble wrap. The task was completed successfully and the project was one of the largest in Europe.

3.2. Foundation for a ball mill in the Góraźdze cement plant

In 2012, work at the Góraźdze cement plant included the foundation for the largest ball mill in Europe. The dimensions of the foundation were 5.2 meters in diameter and 17 meters in length. The foundation required the laying of around 6000 m³ of concrete [15]. In this case, C 30/37 class concrete made of CEM V/A 32.5R-LH composite cement was used to make the massive foundation construction. Due to the density of reinforcement, part of the facility required a concrete mix with limited grain size for aggregates up to 16 mm. The adopted concreting technology assumed the division of work into three stages, and for each of the stages, a concrete laying design and temperature monitoring was developed. Laying the concrete mix was carried out with diagonal layers starting from the axis of the elements.

Temperature monitoring was carried out for 19 days. A maximum temperature of 58.1°C was found 61 hours after the beginning of concrete works and the temperature gradient fluctuated in the range of 20 to 25°C/1 m. After the completion of the work, the visual inspection performed did not show the presence of thermal cracks. The success of the work showed that the multi-component CEMV/A 32.5R-LH cement used in concrete can be suitable for concreting massive constructions.

4. Conclusions

Massive concrete constructions as a result of cement hydration can achieve temperatures as high as 80°C and what is specifically dangerous for the monolithic structure are significant temperature gradients. Threats of this type must be taken into account at the stage of designing the composition of the concrete mix and when choosing the technology for laying the concrete mix.

The use of massive concrete structures where the metallurgical cements contain in its composition a high content of granular blast furnace slag allows to reduce the risk of early thermal cracking of concrete. An indispensable factor for obtaining a durable monolithic construction is the correct selection and care of the concrete, its type and duration should be determined in the design stage of the construction technology project. The thermal effects of the care process should be monitored. Metallurgical cements in massive constructions give the possibility of obtaining concretes with appropriate high durability, but also by taking a pro-ecological approach, reduces CO₂ emissions and the consumption of non-renewable raw materials.

References

- [1] Witakowski P., Technologia budowy konstrukcji masywnych z betonu, XIII Konferencja Naukowa Metody Komputerowe w Projektowaniu Konstrukcji Hydrotechnicznych, Korbielów 2001.
- [2] Klemczak B., Masywne konstrukcje betonowe, XXXIII Ogólnopolskie Warsztaty Pracy Projektanta Konstrukcji, Szczyrk 2018.
- [3] Batóg M., Gołga A., Giergiczny Z., Popiół lotny składnikiem betonu masywnego na fundamenty nowych bloków energetycznych, XXIII Międzynarodowa Konferencja Popioły z Energetyki, Zakopane 2016.
- [4] Gołaszewska, M., Janic, A., Wpływ składu cementu na właściwości reologiczne zapraw z cementów portlandzkich żuźlowych, Zeszyty Naukowe Politechniki Częstochowskiej 2018, seria Budownictwo 24, 80-87.

- [5] BN-62/6738-07, Beton hydrotechniczny, Warszawa 1962.
- [6] ACI 116R. 2000, Cement and Concrete Terminology, Reported by American Concrete Institute 2000.
- [7] Kiernożycki W., Betonowe konstrukcje masywne, Polski Cement, Kraków 2003.
- [8] Klemczak B., Knoppik-Wróbel A., Wpływ wybranych czynników materiałowo-technologicznych na temperatury twardnienia betonu w masywnej płycie fundamentowej, VII Konferencja Dni Betonu, Wisła 2012.
- [9] PN EN 206+A1:2016-12 Beton - Wymagania, właściwości, produkcja i zgodność.
- [10] PN-EN 197-1:2012 Cement - Część 1: Skład, wymagania i kryteria zgodności dotyczące cementów powszechnego użytku.
- [11] PN-B-19707:2013-10 Cement - Cement specjalny - Skład, wymagania i kryteria zgodności.
- [12] PN-EN 14216:2015-09 Cement - Skład, wymagania i kryteria zgodności dotyczące cementów specjalnych o bardzo niskim cieple hydratacji.
- [13] Dobrowolski S., Jarzębowski T., Gajweski R., Masywna płyta fundamentowa nowego bloku energetycznego Elektrowni Bełchatów - praktyczne uwagi z betonowania, Konferencja Dni Betonu 2008.
- [14] Bujak W., Lebensztejn M., Czkwianianc A., Pawlica J., Walendziak R., Budowa nowego bloku energetycznego w Elektrowni Bełchatów, Kwartalnik Łódzki 2008, II(19), 16-21.
- [15] Technologia wykonania masywnej konstrukcji żelbetowej na przykładzie budowy fundamentu pod młyn cementu w Cementowni Góraździe, VII Konferencja Dni Betonu, Wisła 2012.

Betonowe konstrukcje masywne - problemy i zadania dla technologa

STRESZCZENIE:

Przedstawiono podstawowe zagadnienia związane z betonowaniem masywnych konstrukcji betonowych. Opisano specyfikę zagrożeń występujących podczas betonowania oraz aspekty doboru spoiwa do wykonania mieszanki betonowej. Scharakteryzowano cement hutniczy jako składnik betonu masywnego. Wskazano, że cementy zawierające w swoim składzie dużą zawartość granulowanego żużla wielkopieczowego pozwalają na zmniejszenie ryzyka wczesnego termicznego pęknięcia betonu oraz dają możliwość uzyskania betonów o wysokiej trwałości. Stosowanie cementów hutniczych jest także działaniem proekologicznym pozwalającym na obniżenie emisji CO₂ do atmosfery.

SŁOWA KLUCZOWE:

betonowe konstrukcje masywne; ciepło hydratacji; naprężenia termiczne; cement hutniczy