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Correlation factor between heat of hydration and compressive strength of common cement

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HIGHLIGHTS

- Correlation factors between the results of heat of hydration and the compressive strength after 28 days of hardening of about 200 common cements were presented.
- High values of R linear correlation factors for Portland cements CEM I were obtained.
- On the basis of straight line equation and the result of heat of hydration test of Portland cements CEM I after certain time the final, standard compressive strength after 28 days can be calculated with a very low error.

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ABSTRACT

In this paper the results of the research of common and special cements were presented. The scope included about 200 samples of industrial cements produced in 9 manufacturing plants in Poland according to cement standard PN-EN 197-1.

Obtained results indicate that for different cement plants strong correlation between the results of heat of hydration tests and the compressive strength after 28 days of hardening of Portland cement CEM I without mineral additions is observed, irrespectively from strength class of that cement. Even better correlation is observed for particular cement plant. However, in the case of blast furnace cement such relationships are in the borderline between weak and moderate for different cement plants and moderate within one manufacturing plant.

Achieved for particular cement plant high correlation factors allow to estimate with very low error the standard compressive strength of cement after 28 days of hardening on the basis of heat of hydration tests just after 3 days. It especially applies for Portland cement CEM I.

1. Introduction

During the reaction of cement with water, takes place heat emission, typical of the exothermic reaction. The amount of heat emission depends on the fragmentation of the cement, clinker Portland cement phase composition and the type and content of the mineral additives in cement [1,2]. Composite cements with mineral additives have a much lower heat of hydration, compared to Portland cement, for the same fragmentation [1–3]. The amount of mineral additive in cement correlates with the amount of heat and the early strength of cement. As the amount of the mineral additive we observe a reduction amount of heat and the lower strength after 2 days of hardening, as compared with Portland cement without an additive.

In Poland, to composite cements production are used as mineral additives mainly granulated blast furnace slag and siliceous fly ash [1,3] These additives possess pozzolan-hydraulic properties and depending on their properties influence on the final strength after 28 days of hardening. The subject of correlation between hardening exotherm and cements strength is often analyzed in the papers concerning chemistry of cement [4–15]. Approach to the problem is typically scientific, focusing on the explanation of relationship between hydration process exotherm and strength development of cements.

Thielen [11] and Kaszynska [12] obtained exponential relationship between compressive strength and the amount of heat of hydration. In turn, Venaut [13] and Peukert [14] obtained rectilinear relationship between compressive strength and the amount of heat of hydration. It should be underlined, that the authors [11–14] used testing method of the heat of hydration in adiabatic conditions. However, Bobrowicz [15] received very good correlation

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between compressive strength and the amount of heat of hydration, tested by using isothermal method. The author [15] conducted studies of compressive strength and the amount of heat of hydration at temperatures of 0 °C, 10 °C as well as 20 °C and he obtained correlation coefficients higher than 0.90, and, in some cases, even close to 1.00 (0.999). Compressive strength and the amount of heat of hydration using semi-adiabatic method at temperature of 20 °C were studied in this work.

The design of concrete mix composition and estimation of mechanical properties of concrete is a main task of concrete designers and technologists. While designing concrete mix composition in terms of quantity, type and cement strength class the designer uses declaration of performance of cement issued by manufacturer and delivered with particular cement batch. However, for received cement batch the results of compressive strength after 28 days of hardening are not confirmed. Such results would be available at least in 4 weeks within manufacturer autocontrol tests, external control of cement producer or examination by concrete manufacturing plant itself. The proposed way of calculation of strength after 28 days of hardening of standard cement mortars on the basis of the results of cement heat of hydration tests allows a fast proof of cement quality and optional verification of concrete mix composition.

The scope of examinations within the research covered about 200 industrial cements manufactured in 9 plants in Poland according to cement standard PN-EN 197-1 "Cement. Part 1. Composition, specifications and conformity criteria for common cements". Such data base was a basis for defining a correlation factor: strength in function of heat of hydration. The curves equations for these relationships were calculated and determined. Calculations of compressive strength after 28 days of hardening were carried out for all cement plants, based on the equation of curve determinated for the highest coefficient R of Pearson linear correlation [16]. Calculated results were compared to obtained results of compressive strength after 28 days of hardening in order to estimate the errors, for specific cement samples.

Obtained correlations between strength and heat of hydration in linear form allow to calculate with a very low error the compressive strength of cement after 28 days of hardening on the basis of heat of hydration results just after 3 days.

2. Results

Strength tests after 2 or 7 and 28 days were performed according to PN-EN 196-1:2006 "Methods of testing cement – Part 1: Determination of strength". Examinations of cements heat of hydration were conducted in accordance with PN-EN 196-9:2005 "Methods of testing cement – Part 9: Heat of hydration – Semi-adiabatic method". Heat of hydration tests were performed up to 72 h of hardening.

The results for particular cement plants are presented in Tables 1–12. Compressive strength after 28 days calculated based on the equation of curve determinated for the highest coefficient R of Pearson linear correlation and relative errors calculated based on obtained results of compressive strength after 28 days of hardening, are also given in Tables 1–12.

Relationships between compressive strength after 28 days of hardening and the heat of hydration after 12, 24, 48 and 72 h as well as determined curves equations for the same cement type from particular cement plant are presented in Figs. 1–12. Moreover in Figs. 1–12 empirically calculated Pearson linear correlation factor [16] is presented, which the closer to 1 is the linear correlation is stronger, normally it is accepted that:

- <0,2 – no linear correlation,
- 0,2 ÷ 0,4 – weak correlation,
- 0,4 ÷ 0,7 – moderate correlation,
- 0,7 ÷ 0,9 – quite strong correlation,
- >0,9 – very strong correlation.

For the same cement type from different cement plants in Poland the relationships between compressive strength after

Table 1
Strength and heat of hydration of Portland cements manufactured in Cement Plant A.

Cement type	Compressive strength [MPa]		Compressive strength after 28 days [MPa] calculated for R = 0,9103	Relative error [%]	Heat of hydration [J/g] after hours					
	After 2 days	After 28 days			12 h	24 h	36 h	41 h	48 h	72 h
CEM I 42,5N-HSR/NA	34,2	63,7	58,6	−8,1	189	269	307	319	332	357
CEM I 42,5N-HSR/NA	27,0	54,4	56,9	4,6	179	250	281	291	303	328
CEM I 42,5N-HSR/NA	22,5	54,2	56,4	4,1	176	262	293	302	313	337
CEM I 42,5N-HSR/NA	28,1	57	57,6	1,0	183	268	308	321	335	361
CEM I 42,5N-HSR/NA	22,4	52,6	51,9	−1,3	149	237	267	276	286	308
CEM I 52,5N-HSR/NA	35,3	64,6	64,4	−0,3	224	292	335	347	360	384
CEM I 52,5N-HSR/NA	36,7	65,7	65,6	−0,2	231	303	339	349	359	378
CEM I 52,5N-HSR/NA	36,7	65,7	66,6	1,3	237	289	315	324	333	353

Table 2
Strength and heat of hydration of Portland cements manufactured in Cement Plant B.

Cement type	Compressive strength [MPa]		Compressive strength after 28 days [MPa] calculated for R = 0,8612	Relative error [%]	Heat of hydration [J/g] after hours					
	After 2 days	After 28 days			12 h	24 h	36 h	41 h	48 h	72 h
CEM I 32,5R-NA	23,0	51,8	52,6	1,6	155	256	300	312	325	348
CEM I 32,5R-NA	22,4	51,6	51,6	−0,1	134	244	286	297	309	332
CEM I 42,5N-NA	23,6	52,5	53,8	2,5	165	269	312	322	333	352
CEM I 42,5N-NA	25,7	54,6	55,3	1,3	165	286	327	337	346	366
CEM I 42,5R-NA	28,0	55,6	57,1	2,6	214	306	340	348	355	370
CEM I 42,5R-NA	26,6	57,8	57,2	−1,1	185	307	344	352	361	380
CEM I 42,5N-HSR/NA	21,3	50,9	51,3	0,8	143	241	274	284	294	314
CEM I 42,5N-MSR/NA	23,0	54	52,3	−3,2	166	252	288	298	308	329
CEM I 42,5N-MSR/NA	27,0	57,9	55,3	−4,5	174	286	328	337	346	364
CEM I 42,5N-MSR/NA	22,8	51,8	52,1	0,6	156	250	284	293	303	324