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The effect of cement type and plasticizer addition on concrete properties

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HIGHLIGHTS

- Plasticizer types associate of their impact on viscosity of CEM I and CEM II cement.
- Plasticizer more stop hydration of concrete with CEM I than with CEM II cement.
- Plasticizer more worsen concrete with CEM I than with CEM II cement properties.

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ABSTRACT

It is important to select a certain type and amount of plasticizer for successful cement application in concrete. In the paper, the dynamic viscosity test was adopted to verify the impact of the type and dosage of plasticizers lignosulphonates (LS), polycarboxilate acid (P) and polycarboxylate ester (SP) on limestone cement (L) and normal cement (N) paste viscosity. The results show that the SP addition most efficiently reduces viscosity in the pastes of both types of cement, P addition moderately and the LS addition increases viscosity. It has been estimated that the increase of SP content further extends the hydration process in a concrete mixture with N, than in a mixture with L. Examination of the physical–mechanical properties of hardened concrete using both types of cement show that in order to get satisfactory properties of concrete using L cement, the application of a higher amount of SP is recommended. For concrete with N cement a high amount of SP is undesirable, because it slows down the hydration process of cement and concrete properties are significantly deteriorated.

1. Introduction

Currently, one of the main goals in the cement industry is to mitigate CO_2 emissions into the atmosphere. One of the methods used in achieving this goal is manufacturing and using cements where a certain portion of clinker in the cement content is substituted with mineral additions. The most advanced additions from a technological and cost-efficiency prospective are limestone and slag; therefore usage of CEM II in Europe has recently been on the increase. For Lithuanian conditions, the development of limestone-blended Portland cement usage is reasonable, as limestone is a local raw-material which is used in cement manufacturing. Limestone-blended cements have been widely studied [1–6]. The main effects of limestone filler are of a physical nature [7,8]. Data on limestone addition effect on cement pastes are controversial. Some researches maintain [8] that limestone addition mitigates the amount of water consumed for preparation of cement paste of normal thickness, whereas others [7] found that the addition of considerably fine limestone increases the viscosity of the cement paste and W/C ratio, and this influences concrete durability qualities. Limestone has a double impact on concrete strength properties: compared to concrete samples free of limestone addition, a large quantity of limestone (35%) can reduce concrete compression strength by up to 40% after 28 days, and a small content (5–10%) can insignificantly (by 5%) increase concrete compression strength after 2–7 days. Limestone presence in the binding system determines the acceleration of initial cement hydration, especially for tricalcium silicate [2]; therefore choosing an option of plasticizer in concrete with limestone cement is essential. Various plasticizers are widely used in concrete and have become common components, and concrete properties are significantly influenced by such incorporation. The presence of mineral additions such as limestone in cement may affect interaction between the plasticizer and the cement [9]. According to researches [4,10–12], contrary to other types of cement, e.g. pozzolanic cement, with Portland cement all existing types of plasticizer can usually be used. It has been confirmed that during the process of manufacturing high-performance concrete with a low W/C ratio (0.25–0.30), where the usage of superplasticizer (SP) is essential, the impact of limestone addition (up to 15–20%) on concrete strength properties is not significant, when compared to additive free concrete [11,12]; however, such

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Table 1
Characteristics of cements.

Cement type	Specific density (kg/m^3)	Bulk density (kg/m^3)	Compression strength (MPa)		Setting time (min)		H_2O content (%) (norm. consistency)	Fineness		LOI (%)	Insolubility (%)	SO_3 (%)
			7 days	28 days	Initial	Final		By Blaine (m^2/kg)	>90 μm (%)			
N	3200	1200	25.5	55.0	120	175	24.6	3270	2.7	1.32	0.29	2.74
L	3100	1100	23.7	51.1	190	285	25.0	4080	4.3	5.79	–	2.69

Table 2
Mineral composition calculated from XRF-data from.

Cement type	C_3S (wt.%)	C_2S (wt.%)	C_3A (wt.%)	C_4AF (wt.%)	Mg0 (wt.%)	CaOl (wt.%)	K_4CaSO_4 (wt.%)	$CaSO_4(H_2O)_2$ (wt.%)	$CaSO_4$ $(H_2O)_{0.5}$ (wt.%)	$CaSO_4$ (wt.%)	SiO_2 (wt.%)	$CaCO_3$ (wt.%)
N	63.85	7.50	7.06	12.15	2.45	1.16	1.78	1.88	0.61	0.04	0.14	1.38
L	55.33	7.65	6.37	10.66	3.21	0.78	2.92	1.56	0.51	0.09	0.32	10.60

Table 3
Research data on gravel and sand physical and mechanical properties.

Fillers	Fraction	Characteristic	Test results
Coarse filler–Gravel	4/16	Particle density (kg/m^3)	2650
		Water adsorption (%)	1.30
		Bulk density (kg/m^3)	1546
Fine filler–Sand	0/4	Particle density (kg/m^3)	2300
		Water adsorption (%)	0.59
		Bulk density (kg/m^3)	1582

concrete features finer non-touching pores, thus lower permeability, more even structure, and accordingly, it has better performance [13]. It is noted that in further curing periods the strength of such concrete can reduce (7–10%). Some researches maintain that contrary to other high fineness additions, limestone addition does not aggravate, but may even improve the efficiency of some SP [14], however others researches [15,16] indicate the contrary – that the combination of plasticizers has an adverse affect on concrete properties and performance, i.e. mitigates its mobility and plasticity. Currently studies of limestone-blended cements and plasticizers have focused primarily on PCE admixtures and the importance of the molecular weight and structure of the PCE on the rheological behaviour and water-reduction of limestone-blended cement [10]. However, lignosulphonates (LS) and polycarboxilates (P) have been still widely used in concrete as regular water reducing admixtures due to their relatively low cost. Limestone cement is not ductile and manufacturers, who have insufficient experience in choosing the type and amount of plasticizer, are still facing certain rheological, structural formation, compression strength and durability issues. Therefore, the user often prefers to choose CEM I-type cement. Although many studies are performed in this area, interactions between blended cements and various types of plasticizers, as well as the impact of their amount on the concrete hydration process, structure formation and properties, have been insufficiently investigated [10].

Pursuing wider application of limestone Portland cement, comparative analyses of limestone and normal cement with widely applied in concrete industry plasticizers, such as LS, P, and SP should be conducted, and having selected the most suitable option, the effect of the plasticizer amount on properties of both types of cement concrete mixture and hardened concrete should be compared.

2. Materials and research methods

Concrete used to be manufactured from natural raw-materials and its composites and components used to be selected so that they would meet with the requirements for concrete, such as concrete density, strength, durability, manufacturing process and method of execution.

Two-types of Portland cement CEM I 42.5 N (N) and CEM II/A-LL 42.5 N (L), complying with LST EN 197-1: 2011 [17] requirements, were used in the research. Fundamental characteristics of Portland cements and fillers are provided in Tables 1 and 2 below.

Coarse and fine fillers, complying with LST EN 12620:2003 + A1:2008 [18] requirements were used. Coarse filler – gravel fraction 4/16. The content of fragile types of rock, such as sandstone and limestone is not higher than 2%. The data on physical properties of gravel and sand are provided in Table 3 below. For mixing used water was in compliance with LST EN 1008:2005 [19] requirements. (see Table 3).

The following three different types of plasticizers were used in the research: ligninsulphonates-based (LS), synthetic polycarboxylic acid-based (P) and polymer-based synthetic polycarboxylate ester (SP) plasticizer. All plasticizers were used in liquid form. Their properties are provided in Table 4 below. Electric conduction (EL) and pH were defined in the laboratory. Electricity conduction and pH tests of plasticizers were performed with the MPC 227 device (pH electrode InLab 410, measuring accuracy 0;01 S/cm; EL electrode InLab 730, measuring range 0–1000 S/cm). Measuring was conducted at a temperature of 20 °C.

The effect of plasticizers on the dynamic viscosity of cement pastes was tested using the SV-10 vibro-viscosimeter. With the SV-10 vibro-viscosimeter it is possible to define the dynamic viscosity of pastes up to 12,000 mPa s with 0.01 mPa s accuracy in a very small amount of paste (35 ml). This instrument measures paste viscosity resistance to constant vibration of gauge plates at 30 Hz frequency. The proportional to viscosity resistance force is converted into an electrical signal and recorded. The W/C ratio in cement pastes was minimal −0.24 and in all cases constant, thus also enabling measurement of maximal amounts of plasticizers. Cement pastes with plasticizer contents dosed from 0% to 1.25% (depending on cement amount) were prepared for the tests. The dynamic viscosity of the prepared pastes was measured instantly and then after 5, 10, 15, and 20 min. The time chosen for measurements corresponds with actual concrete placing terms.

The 100 × 100 × 100 mm specimens moulded from the prepared blend were kept in moulds for 1 day in normal conditions and then for 27 days hardened in water at a temperature of 20 °C. Manufacturing and hardening of concrete specimens were performed in compliance with LST EN 206-1:2002 and LST EN 12390-2:2009 [20,21], compression strength – according to LST EN 12390-3:2009 [22], and density – according to LST EN 12390-7:2009 [23] requirements. Water absorption was defined following the written Ref. [24]. The ultrasound pulse propagation rate (UWV) was defined according to LST EN 12504-4:2004 [25] requirements. The hardening kinetics of the whole concrete mix can be continuously followed and monitored using an ultrasonic method. This technique is based on the propagation velocity of ultrasonic waves through a sample. It can be applied from the end of mixing to the complete hardened state of the concrete. The Pundit 7 ultrasonic pulse indicator apparatus and datalogger were used for recording measurements. The fresh concrete mix was placed in a cylindrical mould (100 mm diameter and 40 mm high) between two ultrasonic transducers operating at 10 pulses per second and a frequency of 54 kHz. The UWV increased according to the setting of the concrete mix and development of its hardening structure.

The concrete mix hardening kinetic was followed by the exothermic (EXO) profile, according to the Alcoa methodology [26]. The fresh concrete mix heat development, which results from the exothermic reaction of the cement hydration, was

Table 4
Characteristics of plasticizers.

Plasticizer marking	Liquid colour	EL (mS)	pH
LS	Dark brown 1200	13.62	5.76
P	Nearly colourless	1.94	3.89
SP	Whitish	1.67	3.34