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INFLUENCE OF TEMPERATURE ON THE EFFECT OF PLASTIFICATION IN CONCRETE MIXTURES

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Abstract. Demand for plasticisers used in concrete industry is growing in Lithuania and other countries. The paper examines a plasticising admixture based on carboxylate and the influence of temperature on the properties of concrete mixtures. Two types of Portland cement – limestone CEM II/A – LL 42.5R and slag CEM II/A – S 42.5N – have been investigated. To determine the effect of plasticising admixtures on the rheological properties of a concrete mixture, the slump, spread and density of the mixture, along with the depth of cone penetration, were examined. Then, with reference to the obtained data, yield stress was calculated. The research results illustrate the effects specific to certain combinations of plasticising admixtures with different types of cement. A plasticised concrete mixture with limestone Portland cement retains its slump better and remains almost unchanged for 90 min. The slump of the plasticised concrete mixture with slug Portland cement, however, is decreasing gradually for the full period of two hours, from the moment the mixture is ready. At higher temperatures, plastification effect manifests itself in a less intensive manner. Concrete mixtures with slug Portland cement have a higher slump, spread and the depth of cone penetration. A 5 °C increase in temperature (from +15 °C to +20 °C) makes the slump decrease by 32–33% both in concrete mixtures with limestone Portland cement and in concrete mixtures with slug Portland cement.

Keywords: limestone Portland cement, slag Portland cement, plasticiser, slump, flow table, spread, yield stress, cone penetration.

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Introduction

The range of admixtures used in practice is huge due to their chemical composition. However, the ways they interact with cement and aggregates in a concrete mixture have not been sufficiently examined yet. Nevertheless, the conducted experiments show that producing concrete containing such chemical admixtures is a rational option (Rixon 1999; Usherov-Marshak 2005; Aitcin 2000; Kucharska 2000).

The simplest and most effective way to change the properties of concrete mixtures and to improve their quality is the use of chemical additives (Vovk 2006; Usherov-Marshak 2005; Nawy 2001; Rixon 1999). The additives in the concrete mixture, like binding materials, aggregates and water, have become very important, as this is an effective method for producing the concrete of a better quality.

Super – plasticisers now are organic substances that, by their chemical composition, may be classified into the following groups: sulphonated naphthalene formaldehydes, sulphonated melamine formaldehydes, modified lignosulphonates, polycarboxylates and polycarboxylate ethers (Usherov-Marshak 2005; Erdogu 2000; ACI COMMITTEE 212 1989; Mosquet *et al.* 2003; Nawy 2001; Kucharska 2000).

The new generation of superplasticisers based on polycarboxylate and acrylate includes compounds that give concrete mixtures a very high slump at low water

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and cement (water/cement) ratio values (up to 0.28–0.3) in the production of concrete (Usherov – Marshak 2005). When added to concrete mixtures, polycarboxylate admixtures change their structure and become modified. Their main chemical chain is made of molecules with free carboxyl groups, often with sodium salts.

Plasticising admixtures are agents that allow surface films to form, slow down initial hydration, etc. (Łukowski 2003; Usherov-Marshak 2005). The plasticising effect, in turn, is known to depend on the molecular structure, nature, size and position of hydrophilic groups inside it, as well as on molecular mass, etc.

The enormous range of synthesis processes and properties of new varieties of superplasticisers makes it possible to regulate rheological properties and cut the amount of water in concrete mixtures. A superplasticiser added to a concrete mixture may reduce the amount of water by up to 20–40%.

Scientists have been researching plasticisers that prolong the periods of the slump of a concrete mixture (Makishaeva 2006). The concrete mixture with the superplasticiser made from various components can retain its slump for up to three hours. Such concrete gains its strength sooner and also almost escapes sedimentation.

One of the researchers have determined that to achieve the desired slump in concrete with smaller amounts of cement, a larger amount of the superplasticiser is needed (Kapelko *et al.* 2007).

Other researchers have determined that plasticisers and superplasticisers change the rheological properties of cement pastes and concrete mixtures (Daukšys *et al.* 2010; Asaga *et al.* 1980; Ferraris *et al.* 1992). The plasticity of admixtures depends on their chemical composition (Daukšys *et al.* 2010; Aitcin *et al.* 2001).

Currently, one of the most popular plasticisers is based on the carboxylate polymer (Rixon 1999; Usherov – Marshak 2005; Nawy 2001).

With plasticisers, the plastification effect endures for a certain period the length of which needs to be known. The period depends on the type of cement and on environmental conditions such as temperature.

The article analyses the effect of a carboxylate – based plasticiser and temperature on the rheological properties of the concrete mixture.

1. Concrete raw materials and compositions of concrete mixtures

Concrete mixtures were prepared both with a plasticiser and without it.

Limestone Portland cement CEM II/A – LL 42.5R and slag Portland cement CEM II/A – S 42.5N produced by *AB Akmenės cementas* were chosen for research purposes. In this instance, water demand for normal consistency cement paste is 26.0% for limestone Portland cement and 25.6% for slag Portland cement.

Other physical properties of Portland cement are specified in Table 1.

Table 1. Physical and mechanical properties of Portland cement

Parameter	Types of Portland cement	
	CEM II/A – LL 42.5R	CEM II/A – S 42.5N
Specific surface, cm^2/g	4372	3362
Bulk density, kg/m^3	1020	1130
Initial set time, min	160	140
Final set time, min	200	185
Compressive strength following 7 days	29.9	25.4
Compressive strength following 28 days	51.2	54.5

The used aggregates included crushed gravel (fr. 4/16) and sand (fr. 0/4). The characteristics of coarse and fine aggregates are specified in Table 2.

Table 2. Characteristics of aggregates

Parameter	Type of an aggregate	
	Coarse aggregate	Fine aggregate
Particle density, kg/m^3	2540	2570
Bulk density, kg/cm^3	1440	1650
Bulk porosity, %	43.1	35.8

The results of grading aggregates are specified in Tables 3 and 4.

Table 3. The results of grading sand

Sieve size, mm	Residues, %	Passing, %
4 (5)	1.19	98.81
2 (2.5)	12.08	87.92
1 (1.25)	30.47	69.53
0.5 (0.63)	53.39	46.61
0.25 (0.315)	70.92	29.08
0.125 (0.14)	96.95	3.05
0.063 (–)	99.05	0.95

Table 4. The results of grading crushed gravel

Sieve size, mm	Residues, %	Passing, %
31.5 (40)	0	100
16 (20)	1.5	98.5
8 (10)	69.8	30.2
4 (5)	97	2
2 (2.5)	99.77	0.23

Concrete mixtures (C30/37) with two types of composition were prepared for research: B I and B III with Portland cement without the plasticiser and B II and B IV with 1.25% of the plasticiser (Table 5). The water/cement ratio in all concrete mixtures was the same. In the mixtures containing the plasticiser, the amount of water and Portland cement was lower by 20%.

Table 5. The composition of concrete mixtures

	Amounts of materials in 1m^3 of the concrete mixture, kg			
	B I	B II	B III	B IV
Coarse aggregate	790			
Fine aggregate	966			
CEM II/A – LL 42.5R	382	306	–	–
CEM II/A – S 42.5N	–	–	382	306
Water	170	136	170	136
V/C	0.44			
Carboxyment 3220	–	6.32	–	6.32

2. Research methodology

All concrete mixtures were manually mixed in a laboratory. All materials used for research purposes were kept at temperatures +15±1 °C and +20±1 °C and tested at the same temperatures. The temperature of the concrete mixture was measured applying an infrared thermometer AND AD5611 Three methods were employed for determining the consistency of the concrete mixture:

- slump method;
- flow table method;
- cone penetration test.

The concrete mixtures containing 8 litres each were prepared for research. The slump test was done in compliance with the technique set forth in EN 12350 – 2, and the spread table test complied with EN 12350 – 5; however, the cone shape was not standard (bottom diameter – 200 mm, top diameter – 100 mm, height – 300 mm). The depth of cone penetration in concrete was determined using a non – standard method adding 1 kg weight on the cone of a 30° slant angle (Skripkiūnas 2007).

The slump and spread of the concrete mixture as well as the depth of cone penetration were measured every 20 min. The overall testing lasted for two hours.

The yield stress of the mixture not exposed to vibrations was determined using the value of a sinking standard cone (used for slump measurements) and the following equation (Skripkiūnas 2007):

$$\tau_0 = \frac{0,00815 \cdot \rho_m}{\left(\sqrt{\dfrac{0,498}{30 - SL}} - 0,001724 - 0,024\right)^2}, \quad (1)$$

where: τ_0 is yield stress in Pa;

ρ_m is the density of the mixture in kg/m^3;

SL is the sinking cone (slump) in cm.

Additionally, an important property of hardened concrete – its compressive strength following 28 days under the standard EN 12390 – 3 was determined.

3. Test results and discussion

Before turning to the rheological properties of concrete mixtures, have a look at the results related to their density. Table 6 shows that all concrete mixtures have rather similar density varying between 2380 kg/m^3 and 2442 kg/m^3. The density of concrete mixtures with slag Portland cement is slightly higher. This difference is likely to have affected the rheological properties of concrete mixtures.

Table 6. The density of concrete mixtures with different types of Portland cement

Composition of concrete mixtures	Density, kg/m^3	
	CEM II/A – LL 42.5R	CEM II/A – S 42.5N
Without a plasticiser	2380	2390
With a plasticiser (at +15 °C)	2380	2410
With a plasticiser (at +20 °C)	2440	2442

Table 6 shows a trend of higher density in test samples when ambient temperature increases by 5 °C.

Measuring of a concrete mixture's rheological properties started with a slump test at temperature

+15±1 °C. The results are summarised in Figures 1 and 2.

The curves in Figure 1 show that the initial slump of concrete mixtures with different types of Portland cement without plasticising admixtures is very similar. During the first 20 min, the slump was decreasing at the same rate. In 2 hours' time, the slump decreased by 57.5% in the concrete mixture with limestone Portland cement and by 56.4% – in slag Portland cement.

The results of the superplasticiser are different. Figure 2 shows that the concrete mixture with limestone Portland cement and the superplasticiser has higher values of the slump and that such slump persists for about 80 min. The value of the concrete mixture with slag Portland cement and the superplasticiser was lower. Additionally, the slump was decreasing gradually at a constant rate of up to 60 min.

In two hours time, a decrease in the slump of concrete mixtures was observed and made 61.4% in the concrete mixture with limestone Portland cement and the plasticising admixture and by 81.5% in the mixture with slag Portland cement and the plasticising admixture.

Testing concrete mixtures with Portland cement and the superplasticiser at +20 °C produced lower slump values than those at +15 °C (Fig. 3).

After forty minute testing, the slump started decreasing at a higher rate. The trend is that concrete mixtures with limestone Portland cement and the superplasticiser have a better slump. A 5 °C temperature, a change produced a significant decrease in the slump in concrete mixtures.

The research proceeded with the second test – spread table test. The results are summarised in Figures 4 and 5. The tests were carried out at +15 ºC Figure 4 shows that following 20 minutes of testing, the spread flow of concrete mixtures starts decreasing. In 120 min time, the spread flow of the concrete mixture

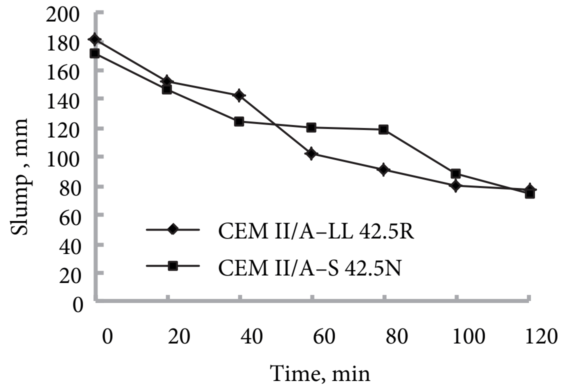

Fig. 1. A concrete mixture with different types of Portland cement and with no dependence of superplasticizer plasticity on time at a temperature of +15 °C

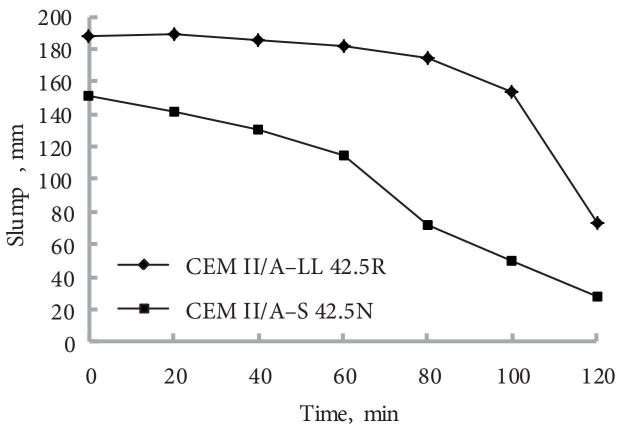

Fig. 2. A concrete mixture with different types of Portland cement and dependence of the superplasticizer having the plasticity of 1.25% on time at a temperature of +15 °C

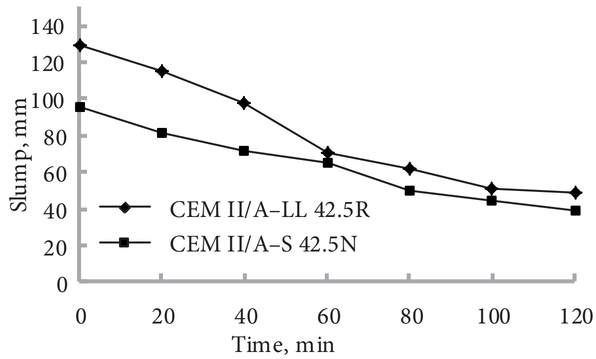

Fig. 3. A concrete mixture with different types of Portland cement and dependence of the superplasticizer having the plasticity of 1.25% on time at a temperature of +20 °C

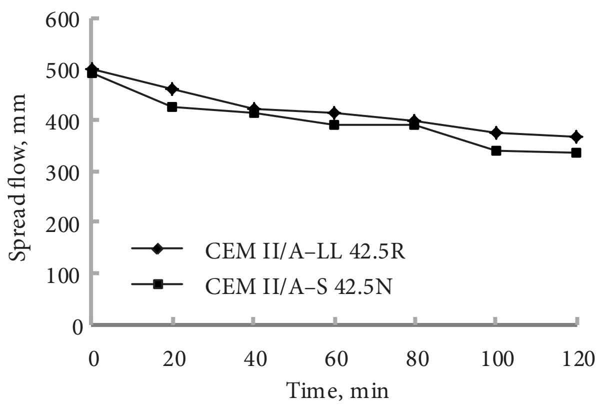

Fig. 4. A concrete mixture with different types of Portland cement and with no dependence of superplasticizer spread flow on time at a temperature of +15 °C

decreased by 26.9% in one case and by 31.6% in the other. Slag Portland cement produced slightly lower spread table values of concrete mixtures.

The graph in Figure 5 shows that following 40 min spread was dropping faster in the concrete mixture with slag Portland cement and the superplasticiser. In the concrete mixture with slag Portland cement and the plasticising admixture, spread, in two hours, decreased by 28.9% and in the mixture with Lime Portland cement and the plasticising admixture by 36.3%.

Figure 6 shows that at +20 °C the spread table values of concrete mixtures with Portland cement starts dropping in 20 min. The trends are similar, though the concrete mixture with slag Portland cement demonstrated a lower spread value.

The research also included cone penetration tests of concrete mixtures with Portland cement, both with and without the superplasticiser at +15 °C. The obtained results are summarised in Figures 7 and 8.

Figure 7 shows that tests on using concrete mixtures with different Portland cement produce similar values of the depth of cone penetration. The initial values of the depth of cone penetration are the same and amount to 75 mm. The values of the depth of cone penetration show equivalent trends of their decrease.

Figure 8 shows that the initial test results of concrete are almost the same. Differences appear following the first 20 min. In 40 min, the depth of cone penetration starts decreasing faster when tested using the concrete mixture with slag Portland cement CEM II/A–S 42.5N. In 120 min, the depth of cone penetration in the mixture with slag Portland cement CEM II/A–S 42.5N was 11 mm lower than that of the concrete mixture with lime Portland cement CEM II/A–LL 42.5R.

Figure 9 shows that the initial values of the depth of cone penetration in concrete mixtures at 20 °C are lower than those at 15 °C. From the beginning, the depth of cone penetration in concrete mixtures is gra-

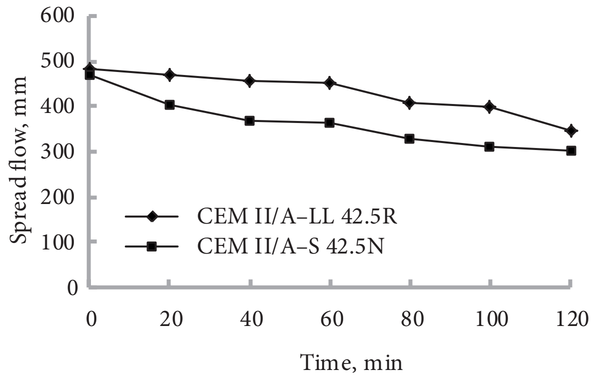

Fig. 5. A concrete mixture with different types of Portland cement and dependence of the superplasticizer having the spread flow of 1.25% on time at a temperature of +15 °C

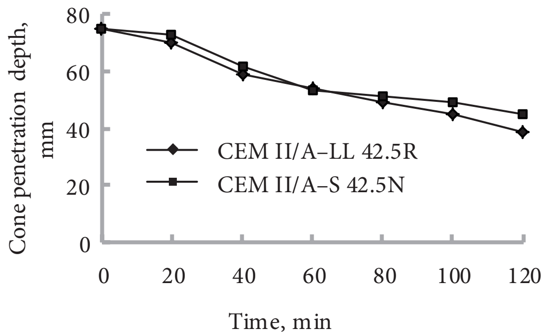

Fig. 7. A concrete mixture with different types of Portland cement and with no dependence of the depth of the cone penetration of the superplasticizer on time at a temperature of +15 °C

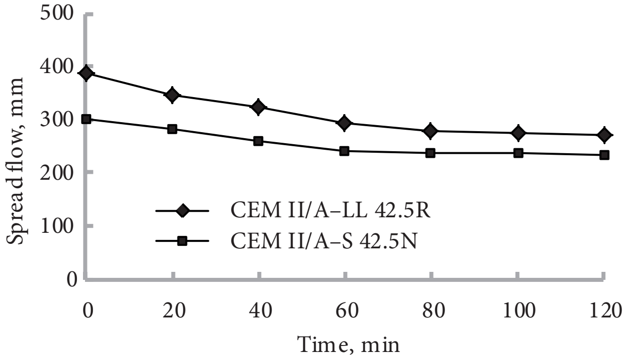

Fig. 6. A concrete mixture with different types of Portland cement and dependence of the superplasticizer having the spread flow of 1.25% on time at a temperature of +20 °C

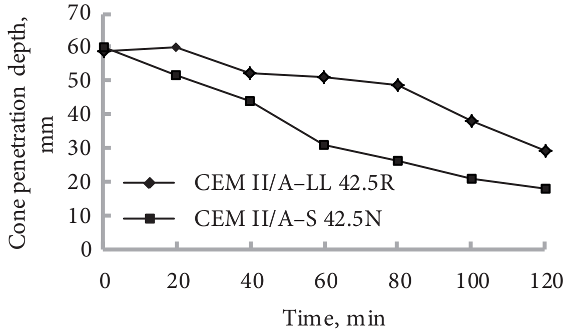

Fig. 8. A concrete mixture with different types of Portland cement and dependence of the depth of the cone penetration of the superplasticizer on time at a temperature of +15 °C

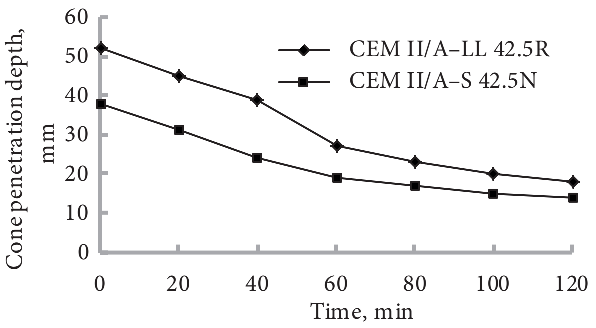

Fig. 9. A concrete mixture with different types of Portland cement and dependence of the depth of the cone penetration of the superplasticizer on time at a temperature of +20 °C

dually decreasing. In 120 min, the values of the depth of cone penetration are more than halved.

Yield stress in concrete mixtures depends on a number of factors: water/cement ratio, the size of aggregates and their concentration in a mixture, the amount of Portland cement, etc. In this research, yield stress was calculated for mixtures with no exposure to vibrations. Calculations were done using Equation 1 and the results are given in Tables 7 and 8. Portland cement CEM II/A–S 42.5N produced higher yield stress of concrete mixtures. This fact is related to the slump values of concrete mixtures.

The conducted research determines that yield stress increases in time, as the slump is decreasing. Such increase of yield stress is caused by a diminishing plasticising effect, as the interaction of liquid and solid phases is changing in concrete mixtures.

A 5 °C increase in ambient temperature causes the yield stress of the concrete mixture to change. Ambient temperature affects the slump of the concrete mixture and raises the limit values of yield stress.

Table 7. The yield stress of concrete mixtures with CEM II/A–LL 42,5R Portland cement

Time, min	Yield stress, Pa		
	B I	B II (+15 °C)	BII (+20 °C)
0	623	581	1071
20	804	575	1095
40	871	599	1225
60	1157	618	1440
80	1240	662	1515
100	1326	797	1608
120	1357	1389	1626

Table 8. The yield stress of concrete mixtures with CEM II/A–S 42,5N Portland cement

Time, min	Yield stress, Pa		
	B III	B IV (+15 °C)	B IV (+20 °C)
0	683	828	1238
20	848	889	1348
40	1001	973	1420
60	1030	1082	1478
80	1044	1414	1604
100	1276	1597	1655
120	1379	1789	1699

During the tests, a few test samples were produced and their compressive strength was measured following 28 days.

The superplasticizer has no effect on the compressive strength of concrete with a reduction in water and cement content in concrete at the same temperature (Table 9). The w/c ratio was the same in all concrete mixtures (Table 3).

Table 9. The samples of the results of compressive strength

Composition of concrete mixtures	Compressive strength, MPa	
	CEM II/A–LL 42.5R	CEM II/A–S 42.5N
Without plasticiser (+15 °C)	43.26	42.17
With plasticiser (+15 °C)	45.23	42.48
With plasticiser (+20 °C)	46.89	43.16

A 5 °C increase in ambient temperature causes a slight increase in the compressive strength of concrete and makes about 1.6–3.67% (Table 7).

Conclusions

1. The concrete mixture with limestone Portland cement preserves a better plastification effect: the slump remains almost unchanged for about 90 min. The slump of the plasticised concrete mixture with slag Portland cement, however, gradually decreases for the full period of 120 min from the moment the concrete mixture is ready.
2. The slump, spread table value and depth of the cone penetration of concrete mixtures with limestone Portland cement are higher than those of the mixtures with slag Portland cement.

3. Increasing temperatures cause a decrease in the effect of admixture plastification. A 5 °C increase in temperature (from +15 °C to +20 °C) causes the slump to decrease by 32–33% both in concrete mixtures with limestone Portland cement and in the mixtures with slag Portland cement.
4. A 5 °C increase in temperature (from +15 °C to +20 °C) causes the yield stress of concrete mixtures to increase. The values of yield stress observed in concrete mixtures with slag Portland cement was higher than those in the mixtures with limestone Portland cement.

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TEMPERATŪROS POVEIKIS BETONO MIŠINIO PLASTIFIKAVIMO EFEKTO TRUKMEI

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Santrauka. Plastiklių poreikis gaminant betoną tiek Lietuvoje, tiek kitose šalyse nuolat didėja. Darbe nagrinėjama plastiklio karboksilatų pagrindu ir aplinkos temperatūros poveikis betono mišinio savybėms. Išbandyti dviejų rūšių portlandcemenčiai klintinis – CEM II/A – LL42,5R ir šlakinis CEM II/A – S 42,5N. Siekiant nustatyti, kokį poveikį daro plastiklis reologinėms betono mišinio savybėms, buvo atlikti betono mišinio slankumo, kūgio įsmigimo į betoną gylio, betono mišinio sklidumo ir betono mišinio tankio tyrimai. Remiantis atliktų tyrimų duomenimis, buvo apskaičiuoti ribiniai šlyties įtempiai. Atliktų tyrimų rezultatai parodo plastiklio naudojimo su skirtingų tipų cementais ypatumus. Betono mišinys su klintiniu portlandcemenčiu plastifikuojamas geriau išlaiko beveik nekintamą mišinio slankumą apie 90 min. Plastifikuoto betono mišinio su šlakiniu portlandcemenčiu slankumas tolygiai mažėja nuo mišinio paruošimo momento iki 2 val. Aukštesnėje temperatūroje mažiau pasireiškia plastifikavimo efektas. Slankumas, sklidumas ir kūgio įsmigimo gylis didesnis betono mišinių su klintiniu portlandcemenčiu. Padidėjus temperatūrai 5 ºC (nuo +15 ºC iki +20 ºC), betono mišinio slankumas tiek su klintiniu, tiek su šlakiniu portlandcemenčiu sumažėja 32–33 %.

Reikšminiai žodžiai: klintinis portlandcementis, šlakinis portlandcementis, plastiklis, slankumas, sklidumas, ribiniai šlyties įtempiai, kūgio įsmigimo gylis.

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