Influence of Multicomponent and Pozzolanic Cements Containing Calcareous Fly Ash and Other Mineral Admixtures on Properties of Fresh Cement Mixtures

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Abstract. The aim of research was to examine usability from technological point of view of cements containing as non-clinker constituents mix of calcareous fly ash (W) and other mineral admixtures - siliceous (V) fly ash, granulated blast furnace slag (S) and limestone (LL). Mixes with CEM II / A-M (V-W), CEM II / B-M (V-W), CEM IV / B-M (V-W) and CEM II / B-M (S-W) are characterized by better workability then mixes with CEM II/B-W and similar workability as mixes with CEM I. Such cements are characterized by acceptable technological properties and can be used as a common cement in a wide application range. Mixes with CEM II/B-M (LL-W) are characterized by worse workability and higher workability loss then mixes with CEM II/B-W and CEM I respectively. The use of cements containing calcareous fly ash W and ground limestone LL is not optimal.

1.  Introduction
Calcareous fly ash (W) is produced as a result of burning brown coal – in Poland, about 5 million Mg of fly ash W is produced each year [1]. Fly ashes (W) are characterized by both pozzolanic and hydraulic activities [1-5]. The pozzolanic activity is determined by the presence of reactive silicon dioxide (SiO2) and alumina (Al2O3) [1-5]. The hydraulic properties of fly ashes (W) are determined by presence of mineral components as quartz, gehlenite, anorthite, anhydrite and calcium oxide and typical cement clinker phases as C2S, C12A7, C4AF, C4A3S [1-5]. One of the largest manufacturers of fly ash (W) is Belchatów power plant. Studies and analyses concerning the use of fly ashes (W) from that power plant proved that quality requirements of EN 197-1 are met and it is possible to use them as a main cement constituent [2,3,5]. It has been shown that the presence of fly ashes (W) in cement usually does not adversely affect the properties of hardened concrete and sometimes even improves them [6-11].

Calcareous fly ashes (W) from Belchatów power plant, likes others fly ashes (W) demonstrates significantly high water demand what results in problems with concrete workability control [2,3]. Performed researches shown that worsening of the workability is directly proportional to the amount of fly ash (W) added [12-16] and increases with sieve residue 0.045 mm increase [3]. Negative influence of fly ash (W) on workability of fresh concrete is the problem which considerably reduces the attractiveness of fly ash (W) use in concrete technology [4]. However, it has been proven that cements produced by blending with processed fly ash (W) or by interginding are characterized by acceptable technological properties and do not differ significantly from other currently used cements [17]. It was shown in [1,3,4,6,14,16,18] that negative influence of fly ash (W) on the workability may be reduced by production of composite cements containing mix of calcareous (W) and siliceous (V) fly ashes,
granulated blast furnace slag (S) and limestone (L, LL). Due to lower water demand these mineral admixtures may partially or even totally eliminate negative influence of fly ash (W) on workability.

The main goal of research was to examine properties of cements containing mix of calcareous fly ash (W) and other mineral components - siliceous (V) fly ash, granulated blast furnace slag (S) and limestone (LL) from technological point of view. In the paper, the results of tests concerning the influence of presence of these additives in CEM II and CEM IV cements produced using different methods on rheological properties, air content, setting times and plastic shrinkage of mortars are presented. Moreover, compatibility of plasticizers with these cements was studied. In a broader aspect, the aim of research is to popularize use of calcareous fly ash (W) in cement and concrete technology, what greatly benefits the environment protection.

2. Experimental

2.1. Research plan and variables

Research plan is shown in Table 3. As variable factors in research were adopted:

- Cement type: presence of other mineral admixtures in cement: siliceous fly ash (V), ground granulated blast furnace slag (S), limestone (LL) (CEM II/A-M (V,W), CEM II/B-M (V,W), CEM IV/B-M (V,W), CEM II/B-M (S,W), CEM II/B-M (LL,W)).
- Method of cement production: (1) by intergrinding of all the constituents (clinker, fly ash (W), other non-clinker constituents (V, S, LL), gypsum in a laboratory ball-mill, (2) by homogenization in blender of earlier prepared materials: Portland cement CEM I 42.5R, raw or ground fly ash (W), other non-clinker constituents (V, ground S, ground LL).
- Processing of fly ash (W) – raw or ground fly ash (W) (in the case of cement produced by homogenization).

As reference cements CEM I and CEM II/B-W and CEM IV/B-W were used.

| Fly ash W content, % | Method of cement production | Blended cement | Intergrodung cement |
|----------------------|-----------------------------|----------------|---------------------|
|                      |                             | W unprocessed  | CEM I               | CEM I (bu) |
| 30                   | CEM II/B-W bu (PL1, PL2)    | CEM II/B-W bp (PL1, PL2) | CEM II/B-W g |
| 50                   | CEM IV/B-W bu               | CEM IV/B-W bp | CEM IV/B-W g |
| 7.5                  | CEM II/A-M (V,W) bu (PL1, PL2) | CEM II/A-M (V,W) bp (PL1, PL2) | CEM II/A-M (V,W) g |
| 15                   | CEM IV/B (V,W) bu (PL1, PL2) | CEM IV/B (V,W) bp (PL1, PL2) | CEM IV/B (V,W) g |
| 15                   | CEM II/B-M (S,W) bu (PL1, PL2) | CEM II/B-M (S,W) bp (PL1, PL2) | CEM II/B-M (S,W) g |

2.2. Cement production methods

Blended cements were produced by homogenization of earlier prepared materials: Portland cement CEM I 42.5R, raw or ground fly ash (W) and other non-clinker constituents (V, ground S, ground LL) in blender ball mill within 5 minutes. Cements produced by blending are marked “bu” when raw fly ash W was used, “bp” when processed fly ash W was used.

Interground cements were produced by intergrinding of all the constituents (clinker, fly ash (W), other non-clinker constituents (V, S, LL) and gypsum) in a laboratory ball-mill until specific surface of
4000 - 4400 cm$^2$/g was obtained. Clinker initially was milled in ball mill to the surface of the 2500 cm$^2$/g. Next clinker was ground together with gypsum to the surface of the 3600-3800 cm$^2$/g. Then fly ash (W) and other additives were added and were ground to get aimed specific surface area. Cements produced by intergrinding are marked “g”.

2.3. Testing methods

2.3.1. Rheological properties. Influence of cements containing fly ash (W) on rheology was tested using mortars. Rheological behaviour of mortar, as of fresh concrete, may be sufficiently described by the Bingham model according to equation:

$$\tau = \tau_o + \eta_{pl} \dot{\gamma}$$  \hspace{1cm} (1)

where: $\tau$ (Pa) is the shear stress at shear rate $\dot{\gamma}$ (1/s) and $\tau_o$ (Pa) and $\eta_{pl}$ (Pas) are the yield stress and plastic viscosity respectively [19,20]. Yield stress determines the value of shear stress necessary for initiating flow. When the shear stress $\tau$ surpasses the yield stress $\tau_o$, flow of the mixture occurs, and the resistance of the flow depends on plastic viscosity $\eta_{pl}$; the higher the plastic viscosity of the mixture is, the slower is its flow. The parameter of particular importance for workability of the mixture is the yield stress $\tau_o$ - its value determines the occurrence of flow of the mixture, and, in consequence, the accurate performance of technological processes of concrete production. The technological meaning of the plastic viscosity $\eta_{pl}$ is marginal in normal concretes. However, the plastic viscosity $\eta_{pl}$ is of significance for self-compacting mixtures workability and stability. It is necessary to notice that studies on rheology of mortars and concretes indicate that results of rheological measurements obtained for mortars may be suitable for prediction of fresh concrete rheology [20-23]. The rheological parameters of mortar or fresh concrete can be measured by applying no less than two considerably different rotation speed $N$ and the measuring the resulting torque $T$ and are determined by regression analysis according to the relation:

$$T = g + h N$$  \hspace{1cm} (2)

where $g$ (Nm) and $h$ (Nm s) are rheological constants corresponding to yield stress $\tau_o$ and plastic viscosity $\eta_{pl}$ respectively. After determining measurement constants of rheometer one may, if necessary, represent the values $g$ and $h$ in physical units. According to [19], in the apparatus like the one used in this work, $\tau_o = 7.9$ $g$ and $\eta_{pl} = 0.78$ $h$.

The mixer and mixing procedure of mortars were compliant with PN-EN 196-1:2006 “Methods of testing cement. Determination of strength”; plasticizers were added 30 sec. after water addition. After mixing mortars samples were transferred to Schleibinger Viskomat NT rheometer and tested. After the end measurement, the mortars were stored in mixer and remixed for 2 min before the next measurement. Additionally, flow test in acc. with PN-EN 1015-3:2000/A1:2005 “Methods of test for mortar for masonry. Determination of consistence of fresh mortar (by flow table) was performed”.

2.3.2. Air content in mortar. Air content in mortars was tested after end of mixing in acc. with PN-EN 1015-7:2000 “Methods of test for mortar for masonry. Determination of air content of fresh mortar”.

2.3.3. Setting times of mortars. Setting times of mortars were tested in acc. with PN-EN 480-2:2008 “Admixtures for concrete, mortar and grout. Test methods. Determination of setting time”.

2.3.4. Plastic shrinkage of mortars. Plastic shrinkage was investigated using Schleibinger Schrinkage Cone [24]. The tests were performed on mortars analogous to rheological tests, at a temperature of 20°C and a relative humidity of 60% (the apparatus was placed in a climatic chamber).
2.3.5. **Heat hydration of cement.** Heat of hydration of the cement was determined with isothermal microcalorimeters TamAir. With this apparatus, one determines the amount of heat in J/g that is emitted in isothermal conditions during cement hydration from the moment of its contact with water. Measured is the heat stream that forms during the cement hydration process in comparison to inert referential sample of analogous heat capacity. The measurement is conducted on sample weighting 5 g, mixed with 2.5 g of water. During the measurement, temperature of the cement paste was 20°C. Measurement of the heat of hydration had lasted 72 hours.

2.4. **Materials and compositions**

Properties of cements are presented in table 2. Properties of plasticizers are presented in table 3. Proportions of mortars used for testing rheological properties and plastic shrinkage are shown in table 4. In the other tests proportioning of mortars was in acc. with requirements of adequate standards. Standard sand in acc. with PN-EN 196-1 was used.

| Table 2. Composition and properties of cements. |
|-----------------------------------------------|
| Cement | Constituents, % | Density, g/cm³ | Water dem., % | Specific surface, cm²/g | Compressive strength 28 days, MPa |
|--------|-----------------|---------------|---------------|-------------------------|-----------------------------------|
| CEM I  | 100 Clink. W V/S/ LL Gips. | 3.09 | 27.6 | 3630 | 50.2 |
| CEM I (g) | 95 | 5 | 3.10 | 25.8 | 3810 | 59.2 |
| CEM II/B-W bu | 70 - 30 | - | 2.95 | 28 | 3570 | 49.6 |
| CEM II/B-W bp | 70 - 30 | - | 2.99 | 31 | 4070 | 53.4 |
| CEM II/B-W g | - 67.7 29 | 3.3 | 2.98 | 30.4 | 4030 | 51.1 |
| CEM II/A-M (V,W) bu | 85 - 7.5 7.5 | - | 3.06 | 26.8 | 3960 | 51.6 |
| CEM II/A-M (V,W) bu | 70 - 15 15 | - | 2.77 | 27.4 | 3840 | 47.6 |
| CEM I/V/B (V,W) bu | 50 - 25 25 | - | 2.74 | 28.6 | 3700 | 34.6 |
| CEM II/A-M (V,W) bp | 85 - 7.5 7.5 | - | 2.88 | 25.9 | 3880 | 53.1 |
| CEM II/B-M (V,W) bp | 70 - 15 15 | - | 2.84 | 26.2 | 3820 | 50.9 |
| CEM I/V/B (V,W) bp | 50 - 25 25 | - | 2.84 | 26.9 | 3820 | 37.7 |
| CEM II/A-M (V,W) g | - 80.5 7.1 7.1 5.3 | 2.82 | 27.4 | 3970 | 54.9 |
| CEM II/B-M (V,W) g | - 66.7 14.3 14.3 4.7 | 3.16 | 28.6 | 4130 | 47.7 |
| CEM I/V/B (V,W) g | - 48.1 24 24 3.9 | 3.19 | 29.6 | 4130 | 36.4 |
| CEM II/B-M (S,W) bu | 70 - 15 15 | - | 2.99 | 30.8 | 3810 | 56.7 |
| CEM II/B-M (S,W) bp | 70 - 15 15 | - | 3.01 | 31.2 | 4060 | 56.9 |
| CEM II/B-M (S,W) g | - 64.7 15.3 15.3 4.7 | 3.00 | 28.2 | 4060 | 56.6 |
| CEM II/B-M (L,L,W) bu | 70 - 15 15 | - | 2.96 | 30.4 | 4230 | 45.1 |
| CEM II/B-M (L,L,W) bp | 70 - 15 15 | - | 2.98 | 30.6 | 4340 | 46.0 |
| CEM II/B-M (L,L,W) g | - 64.7 15.3 15.3 4.7 | 2.97 | 27.2 | 4430 | 47.4 |

| Table 3. Properties of plasticizers |
|-----------------------------------|
| Type | Dosage |
|------|--------|
| PL1  | lignosulfonate | ½ max = 0.25% |
| PL2  | iminodiethanol, bis ethanol, phosphate (V) tri butyl acetate, formaldehyde, methanol, (Z)-octadec-9-enyloamine | ½ max = 0.25% |

| Table 4. Mortar proportioning |
|-------------------------------|
| Content, g/batch |
| Cement | 450 |
| Sand | 1350 |
| Water | 247.5 |
| w/c | 0.55 |
3. Results and discussion
Influence of cements CEM II and CEM IV on rheological properties, air content, setting times, plastic shrinkage of mortars and heat of hydration of cements are presented on figures 1 - 4 and in table 5.

Table 5. Flow, air content, setting times of mortars, heat of hydration of cements

| Cement                      | Flow, mm 5 min | Flow, mm 90 min | Air, % | Setting time, min initial | Setting time, min end | Hydration heat, J/g 12 h | Hydration heat, J/g 24 h | Hydration heat, J/g 48 h | Hydration heat, J/g 72 h |
|-----------------------------|----------------|-----------------|--------|---------------------------|------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| CEM I                       | 21.5           | 19.7            | 5.4    | 121                       | 215                    | 59.76                    | 146.1                    | 219.0                    | 250.0                    |
| CEM I (g)                   | 20.8           | 17.8            | 2.5    | 135                       | 180                    | 66.96                    | 161.1                    | 227.8                    | 266.6                    |
| CEM II/B-W bu               | 20.4           | 17.3            | 3.4    | 188                       | 298                    | 45.21                    | 117.7                    | 196.7                    | 226.5                    |
| CEM II/B-W bp               | 21.2           | 19.3            | 3.5    | 186                       | 296                    | 45.45                    | 124.0                    | 191.9                    | 227.1                    |
| CEM II/B-W g                | 20.7           | 17.0            | 2.6    | 180                       | 250                    | 50.47                    | 149.7                    | 211.5                    | 241.2                    |
| CEM II/A-M (V,W) bu         | 22.1           | 19.5            | 2.2    | 171                       | 241                    | 42.48                    | 120.4                    | 192.8                    | 221.2                    |
| CEM II/B-M (V,W) bu         | 22.6           | 20.0            | 2.1    | 258                       | 428                    | 32.34                    | 99.57                    | 171.6                    | 198.4                    |
| CEM IV/B (V,W) bu           | 23.0           | 19.4            | 2.4    | 202                       | 442                    | 26.79                    | 80.70                    | 149.9                    | 175.7                    |
| CEM II/A-M (V,W) bp         | 22.7           | 20.5            | 2.2    | 166                       | 291                    | 41.68                    | 127.0                    | 194.5                    | 223.1                    |
| CEM II/B-M (V,W) bp         | 23.2           | 21.1            | 2.5    | 184                       | 359                    | 39.28                    | 117.9                    | 180.1                    | 206.9                    |
| CEM IV/B (V,W) bp           | 22.9           | 21.5            | 2.2    | 274                       | 449                    | 26.67                    | 84.30                    | 142.0                    | 166.8                    |
| CEM II/A-M (V,W) g          | 21.4           | 19.6            | 2.2    | 135                       | 180                    | 43.37                    | 118.4                    | 217.9                    | 255.3                    |
| CEM II/B-M (V,W) g          | 21.8           | 20.3            | 2.2    | 156                       | 268                    | 34.44                    | 106.7                    | 207.3                    | 236.8                    |
| CEM IV/B (V,W) g            | 22.3           | 19.9            | 2.2    | 192                       | 298                    | 27.52                    | 89.07                    | 183.2                    | 207.2                    |
| CEM II/B-M (S,W) bu         | 22.3           | 20.0            | 1.8    | 168                       | 306                    | 50.32                    | 130.6                    | 183.6                    | 210.5                    |
| CEM II/B-M (S,W) bp         | 21.8           | 18.7            | 2.3    | 181                       | 296                    | 53.43                    | 133.5                    | 188.2                    | 215.2                    |
| CEM II/B-M (S,W) g          | 19.5           | 16.7            | 2.3    | 170                       | 290                    | 50.55                    | 124.4                    | 220.3                    | 251.8                    |
| CEM II/B-M (LL,W) bu        | 20.7           | 17.8            | 2.2    | 175                       | 250                    | 57.40                    | 136.3                    | 188.1                    | 214.4                    |
| CEM II/B-M (LL,W) bp        | 21.5           | 17.5            | 2.3    | 174                       | 254                    | 57.23                    | 136.0                    | 187.5                    | 213.9                    |
| CEM II/B-M (LL,W) g         | 19.0           | 16.8            | 2.5    | 150                       | 370                    | 56.02                    | 130.91                   | 219.2                    | 245.2                    |

3.1. CEM II/A-M (V-W), CEM II/B-M (V-W), CEM IV/B-M (V-W) cements
Mortars with CEM II/B-M (V,W) cements are characterized by significantly lower yield stress g and similar or slightly lower plastic viscosity h than the mortars with CEM II/B-W cements, even lower than mortars with cement CEM I. Changes of rheological properties in time of CEM II/B-M (V,W) mortars are clearly lower than of CEM II/B-W mortars and even of CEM I mortars when blended cement with processed W or interground cement are used. Thus, presence of V in the cement allows to overcome the negative impact of W on the rheological properties of mortars. It should be noted, that the quantity of V and W in cement affects only to a small extend the rheological properties of mortars. Therefore, using fly ash W as cement component together with V fly ash, it is possible to utilize higher content of W fly ash overcoming its negative impact on rheology. Considering workability, it is preferable to use the interground or blended with processed fly ash W cements.

Figure 1. Rheological properties of mortars made of CEM II/A,B-M (V,W), CEM IV/B-M (V,W)
In relation to the mortars with CEM I cement, cements with fly ashes W and V do not affect or contribute to reduction of the amount of air in the mortar. Effect of CEM II/B-M (V-W) cements and CEM II/B-W cements on the amount of air in mortar is analogous. Cements with V and W fly ashes are characterized by delayed initial and final setting times in relation to cements with CEM I. Delay of the initial setting time is not explicitly connected to the amount of fly ashes and the cement production process. Plastic shrinkage of mortar with cement CEM II/B-M (V-W) is higher than of mortars with CEM II/B-W and CEM I. Cements containing both W and V fly ash and cements CEM I initially are characterized by a similar amount of heat generated during the process of hydration. In the period from 12 to 72 hours the amount of heat generated by cements with W and V fly ashes is lower than cements CEM I - in the case of CEM II/A-M (V-W) by approx. 10%, CEM II/B-M (V-W) approx. by 20%, CEM IV/B-M (V-W) by approx. 30%.
3.2. CEM II/B-M (S-W) cements
Mortar with cements CEM II/B-M (S-W) are characterized by lower yield stress $g$ than the mortars with CEM II/B-W cements and similar yield stress $g$ in comparison to CEM I mortar. The increase in the yield stress $g$ in time for mortars with blended CEM II/B-M (S-W) cements is lower than for CEM II/B-W mortars and similar or higher than of CEM I mortar. Mortars with blended CEM II/B-S cements have a higher, and mortars with interground cements CEM II/B-S analogous plastic viscosity $h$ as mortar with CEM I. Plastic viscosity $h$ of mortar with CEM II/B-M (S-W) cement does not change in time. In general, presence of slag S allows to reduce the negative impact of fly ash W on the rheological properties of mortars, but to a lesser extent than the corresponding addition of fly ash V.

Cement CEM II/B (S-W) does not affect or contribute to reduction of the amount of air in the mortar in relation to the mortars with cement CEM I. Effect of cements CEM II/B (S-W) and CEM II/B-W on the amount of air in mortar is analogous. Mortars with CEM II/B (S-W) cements in relation to CEM I are characterized by delayed initial and final setting time. In relation to the CEM II/B-W mortars setting time, the initial setting time of CEM II/B (S-W) is similar, but the final setting time can be shorter. Plastic shrinkage of mortar with CEM II/B-M (S-W) is higher than of mortar with CEM I and similar like mortar with CEM II/B-W. Cements CEM II/B (S-W) and cements CEM I initially are characterized by a similar amount of heat generated during the hydration process. In the period from 12 to 72 hours the amount of heat generated by the cements CEM II/B (S-W) is reduced by approx. 7 - 15%.

3.3. CEM II/B-M (LL-W) cements
Mortars with cement CEM II/BM (LL-W) obtained by blending have a similar yield stress $g$ to mortars with CEM II/B-W and higher yield stress $g$ than mortars with cement CEM I. The increase of the yield stress $g$ in time of mortar with this cement is higher than in case of both mortar with cement CEM II/B-W and CEM I. Changes of yield stress $g$ of the mortar in time are smaller than in case of mortar with CEM II/B-W and at the same time higher than of the mortar with CEM I. Mortars with blended cements CEM II/B-M (LL-W) have higher, and mortars with cement interground has analogous plastic viscosity $h$ as mortar with CEM I. The presence of limestone LL does not reduce the negative impact of fly ash W on the rheological properties of mortars. Only mortar with cement CEM II/B-M (LL-W) hp has an initial rheological properties similar to the CEM I and CEM II/B-W mortars, but workability loss of that mortar is clearly higher.

Cements CEM II/B (LL-W) does not affect (interground) or contribute (blended) to reducing the amount of air in the mortar in relation to the mortars with cement CEM I. In comparison to CEM I, cement CEM II / B (LL -W) has a delayed initial and final setting time. However, in relation to the CEM II/B-W initial and final setting time of CEM II/B (LL-W) are speed up, especially in the case of cement blended with ground fly ash W. The plastic shrinkage of mortar with CEM II/B (LL-W) is slightly higher then mortar with CEM I. In the period from 12 to 72 hours the amount of heat generated by cement CEM II / B (LL-W) is lesser than CEM I, after 72 h by approx. 10 - 15%.

3.4. Effectiveness of plasticizers with cements CEM II/B-W and CEM II/B-M
The influence of plasticizers PL1 and PL2 on rheological properties of the mortars is shown in Figures 5 - 6, and on the setting time, air-content of mortars and cement heat of hydration in table 6. In presence of all cements CEM II containing fly ash W, plasticizers PL1 and PL2 work effectively, lowering the yield stress $g$ and plastic viscosity $h$ and slowing down the changes of rheological parameters in time. Importantly, the yield stress $g$ of mortars with CEM II/B-W and CEM II/B-M cements containing fly ash W, after addition of plasticizer in amount of ½ of maximal dose is usually lower after 5 min than in case of mortars with cement CEM I with analogous plasticizer dose, and for plasticizer PL2 this effect lingers even up to 90 min. Comparing the effects of both plasticizers it can be seen, that PL1 works better with cements CEM II/B-W and CEM II/B-M(V,W), while PL2 better fluidizes mortars with cements CEM II/B-M (S,W) and CEM II/B-M(LL,W). This means that the proper selection of plasticizer requires experimental optimization. Plasticizer PL2 strongly lowers the plastic viscosity of
mortars with all of tested cements, most probably due to the air-entraining properties of this admixture (plasticizer PL1 does not exhibit those properties).

Table 6. Influence of plasticizer on properties of mortars

| Cement                        | Air, % | Initial setting time, min | Hydration heat, J/g  |
|-------------------------------|--------|---------------------------|----------------------|
|                               |        | 12 h | 24 h | 48 h | 72 h |
| CEM I                         | 5.4    | 182  | 59.76| 146.1| 219.0| 250.0 |
| CEM I + PL1                   | 4.1    | 301  | 30.853| 107.0| 211.9| 249.5 |
| CEM I + PL2                   | 20.5   | 349  | 45.45| 124.0| 191.9| 221.7 |
| CEM II/B-W                    | 2.5    | 219  | 33.774| 56.946| 181.8| 225.6 |
| CEM II/B-W + PL1              | 2.1    | 385  | 39.28| 117.9| 180.1| 206.9 |
| CEM II/B-W + PL2              | 10.5   | 444  | 20.219| 37.864| 158.2| 198.6 |
| CEM II/B-M (V-W)              | 2.5    | 337  | 53.43| 133.5| 188.2| 215.2 |
| CEM II/B-M (V-W) + PL1        | 2      | 493  | 20.219| 37.864| 158.2| 198.6 |
| CEM II/B-M (V-W) + PL2        | 13     | 564  | 20.219| 37.864| 158.2| 198.6 |
| CEM II/B-M (S-W)              | 2.3    | 247  | 53.43| 133.5| 188.2| 215.2 |
| CEM II/B-M (S-W) + PL1        | 2.4    | 278  | 53.43| 133.5| 188.2| 215.2 |
| CEM II/B-M (S-W) + PL2        | 11.5   | 322  | 20.219| 37.864| 158.2| 198.6 |
| CEM II/B-M (LL-W)             | 2.3    | 260  | 57.23| 136.0| 187.5| 213.9 |
| CEM II/B-M (LL-W) + PL1       | 1.8    | 398  | 20.219| 37.864| 158.2| 198.6 |
| CEM II/B-M (LL-W) + PL2       | 11     | 461  | 26.198| 48.485| 176.9| 224.12|

Figure 5. Influence of plasticizer PL1 on rheological properties of mortars made of CEM II/B-M

Figure 6. Influence of plasticizer PL2 on rheological properties of mortars made of CEM II/B-M

Plasticizer PL1 virtually does not affect (slightly lowers) the aeration, and plasticizer PL2 air-entrains the mortar. This air content in case of mortars with cements containing fly ash W amounts from 10 to 13% and is significantly lower than in case of mortars with cement CEM I. Plasticizers delay the initial setting time of mortars, but in case of mortars with CEM II/B-M cements containing fly ash W this
effect is clearly lower than in case of CEM I mortars. Plasticizer PL2 lowers the amount of heat generated during hydration in first 12 and 24h, however after 72 h its effect disappears.

4. Conclusions
Multicomponent and pozzolanic cements containing calcareous fly ash W and other mineral admixtures - siliceous fly ash V, granulated blast furnace slag S and limestone LL are characterized by acceptable technological properties and can be used as a common cements in a wide application range. It is recommended to use cements produced by intergrinding of the constituents or blending with fly ash W processed by grinding.

Mortars with CEM II/A,B-M (V-W), CEM IV/B-M (V-W) and CEM II/B-M (S-W) are characterized by higher workability then with CEM II/B-W and similar workability as mixes with CEM I. Using such cements can reduce or even eliminate the negative influence of fly ash W on the workability.

Mixes with CEM II/B-M (LL-W) are characterized by a similar or worse workability and higher workability loss then mixes with CEM II/B-W and CEM I respectively. From the point of view of improving the conditions of designing the workability, the use of cements containing calcareous fly ash W and ground limestone LL it is not optimal.

Moreover, in comparison to CEM I, multicomponent and pozzolanic cements containing calcareous fly ash and other mineral admixtures contribute to: reduction of the amount of air in the mortars, delaying initial and final setting time of mortars, increase of plastic shrinkage and reduction of the amount of heat generated during hydration (during the period of 12 - 72 hours by 10 to 30%);

The effectiveness of plasticizers in presence of CEM I cements. CEM II/B-W and CEM II/B-M do not differ significantly or even increases. The method of production of cement does not significantly affect the effectiveness of plasticizers.

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