THE RHEOLOGICAL PROPERTIES OF FRESH CONCRETE AND MORTAR WITH HIGH CALCIUM FLY ASH IN THE VARIABLE TEMPERATURES

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ABSTRACT

The object of the analysis was to predict the rheological properties of fresh concrete made on cements with High Calcium Fly Ash (HCFA) and other mineral additives such as silica fly ash, limestone and slag based on the properties of the mortar. The composition of mortar was designed in three ways. In the first way the mortar was treated as a product of coarse aggregate surface area and thickness calculated paste coating. In second sequence mortar was designed as a similar composition to the composition of the fresh concrete without adjustments. In the third stage mortar was designed similar to the composition of the fresh concrete with the adjustment of the volume of water calculated from the condition of water demand for consistency. Rheological parameters of mortars and cement paste were determined using a rheometer Viskomat NT and for the fresh concrete using the Viskomat XL in the configuration different temperatures: 10^{0}C, 20^{0}C and 30^{0}C.

Keywords: rheological properties; high calcium fly ash; fresh concrete; mortar

INTRODUCTION

In technological practice the predominant method used in order to calculate the composition of the fresh concrete are the methods of successive approximations, which with the usage of failure and durability condition are determining the size of water cement ratio w/c and type of cement and mineral admixture. Consequently the amount of fresh concrete's trial batches needed to produce the final composition of the self compacting fresh concrete is high. The possibility to determine the properties of the fresh concrete on the basis of the properties of mortar are for many reasons advantageous for technology of concrete. It entails savings of time and materials used in the studies. There are certain limitations posed by the omission of coarse aggregate, which are related with water demand of coarse aggregate, capillary phenomena in the aggregate composition, or with the friction between the particles of aggregate. There is no doubt, that in case of a good knowledge of the impact of the rheological properties of mortar on the rheological properties of the fresh concrete, the amount of trial batches of fresh concrete can be reduced. In [1, 2, 3, 4] it is shown that the results of research on mortars can be used to predict the directions and sizes of changes in the rheological properties of fresh concrete. However, the attempt to check, which of the methods of mortar designing enables more accurate prediction of the rheological properties of the fresh concrete, has not been made so far. Therefore, the researches of the relationship between rheological parameters of mortars, which compositions were calculated by three methods and the rheological properties of the fresh concrete, were conducted. At first, the volume of the paste was treated as a product of coarse aggregate surface area and thickness of the envelope calculated paste (mortar Z1). Then, the mortar which composition was similar to the composition of the fresh concrete without corrections (mortar Z2), was designed. Whereas, in the third stage the composition of the mortar was designed analogous to mixtures with the adjustment of the amount of water calculated from the condition of water demand for the assumed consistency (mortar Z3).

THE RHEOLOGICAL PROPERTIES AND THEIR MEASUREMENT

The laboratory studies have shown and it has commonly accepted, that rheological behavior of mortar and concrete may be sufficiently enough described by the Bingham model according to equation [5]:

$$\tau = \tau_0 + \mu_p \cdot \dot{\gamma} \qquad (1)$$

Where: τ (Pa) is the shear stress at shear rate γ (1/s) and τ_0 (Pa) and η_p (Pa·s) are the yield stress and plastic viscosity, respectively. Yield stress determines the value of shear stress necessary for initiating flow. When the shear stress surpasses the yield stress, the flow of the mixture occurs and the resistance of the flow depends on plastic viscosity; the bigger the plastic viscosity of the mixture, the slower it can flow. It should be noted that yield stress and plastic viscosity increase as maximum particle size increases [6]. Therefore, rheological parameters of concrete are evidently higher than those of mortars. The issues of rheology of mortars and concrete are discussed in detail in [5]. In rheometry the Bingham model equation (1) was used in its conventional form:

$$M = g + N\,h \qquad (2)$$

where g (Nmm) and h (Nmms) are parameters corresponding to the yield stress and plastic viscosity. The rheological parameters of mortars were determined by using a Viskomat NT. Rheometer and the rheological parameters of fresh concrete were determined by using a Viskomat XL (Fig.1). The rotational speed of the probe of mortar varied between 10 and 120 rpm for 70 seconds, whereas the fresh concrete between 10 and 60 rpm for 180 seconds. The results show for decreasing velocity. The rheological parameters of mortars and fresh concrete were determined after 5 and 90 min, counting from the time of mixing mortar. The temperature of the mortar during measurements was kept at a preset level on the automatic thermostatic system.

Figure 1. Rheometers: Viskomat NT (left), Viskomat XL (right).

RESEARCH METHODOLOGY

The fresh concrete and mortar used in the study were designed with similar cements; their composition and physical and chemical properties are shown in Table 1 and 2. High calcium fly ash was used as supplied without grinding. It was characterized by a density of 2.62 g/cm^3 , amount of CaO - 1.18%, the fineness-sieve residue 45µm - 57.2% and the Blaine specific surface - 1900 cm^2/g. The study used a chemical based plasticizer: Iminodiethanol, bis ethanol, phosphate (V) tri-butyl, formaldehyde, methanol, (Z)-octadec-9-enyloamina, the amount of 1% m.c. Sand Point had a value of 40%, the outer surface of sand - 731.6 dm^2/kg and coarse aggregate - 66.2 dm^2/kg.

Table 1. Composition and physical properties of cements.

	COMPONENT, %							
COMPONENT	CEM I	High calcium fly ash W	Silica fly ash V	Limestone LL	Slag S	Gypsum	Density, g/cm^3	Blaine specific surface, g/cm^2
CEM II/A-W	81.1	14.3	-	-	-	4.6	3.04	4190
CEM II/B-W	67.7	29.0	-	-	-	3.3	2.98	4030
CEM II/A-M (V-W)	80.5	7.1	7.1	-	-	5.3	3.02	3970
CEM II/B-M (LL-W)	64.7	15.3	-	15.3	-	4.7	2.97	4430
CEM II/B-M (S-W)	64.7	15.3	-	-	15.3	4.7	3.00	4060

Table 2. The chemical composition of cement.

COMPONENT	LOI	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O
CEM II/A-W	2.01	22.38	6.60	2.54	61.29	1.06	0.16	0.25
CEM II/B-W	2.19	23.89	8.71	3.07	56.56	1.19	0.15	0.26
CEM II/A-M (V-W)	1.88	23.97	7.23	2.76	58.60	1.15	0.40	0.29
CEM II/B-M (LL-W)	6.10	19.60	6.15	2.30	60.68	1.03	0.14	0.22
CEM II/B-M (S-W)	1.92	24.49	6.99	2.44	57.91	1.77	0.19	0.30

The methodology adjustments mortar composition

Compositions of fresh concrete and mortars are presented in table 3. For the purposes of this research the rheological properties of three mortars Z1, Z2 and Z3 and concrete mixes are specified. The composition of the mortar Z2 came directly from the composition of the fresh concrete. Mortars Z1 and Z3 are adjusted compositions of the mortar Z2. The correction of the mortar Z1 was to approach the volume of cement paste needed to ensure a thick coating on the aggregate with the thickness dependent on stack of syringomyelia in the concentrated state and volume of cement paste in the fresh concrete. The main assumptions of the correction are based on method of calculating the distance between particles of aggregate in the fresh concrete as described in [7]. The correction of mortar Z3 was to subtract the amount of water from the mortar due to water demand of coarse aggregate calculated according to Stern. The methodology of calculating the aggregate's water demand is described in detail in [8] and does not require excessive explanation. However, it is necessary to discuss the adjustment of mortar Z1. Thickness of the cement paste's coating, on the grains of aggregate was calculated as a quotient of the volume of paste permeating intergranular spaces in the clastic stack, to the surface of aggregate. At the same time, the leaven permeating the intergranular spaces was assumed as a difference between the total amount of cement paste in the fresh concrete, and the amount of paste required to fill the cavities in the dense clastic stack of aggregate. It is necessary to determine the syringomyelia of aggregate in the concentrated state. The volume is the product of the aggregate's syringomyelia in the concentrated state and its volume in the fresh concrete. The thickness of the coating of paste on the grains of aggregate can be calculated as the quotient of volume of the paste and the surface of coarse and fine aggregate. The way to determine the surface area of the aggregate is to perform the sieve analysis of clastic stack used in the implementation of fresh concrete and to calculate on its basis the developed surface area of clastic stack. Using the thickness of the coating of cement paste on the grains of aggregate, we can calculate the volume of cement paste, which is needed for the surroundings - fractions. In calculating the composition of the mortar, the surface area of coarse aggregate will be the surface area of coarse aggregate included in the fresh concrete. The calculated volume of paste ("taken away from" the surface of coarse aggregate) should be used to modify the composition of the mortar of fresh concrete.

Table 3. Composition of fresh concrete and mortar to test the rheological properties.

	The composition of the 1m^3 [kg]			
	Fresh concrete	Mortar Z1	Mortar Z2	Mortar Z3
Cement	350	485	600	637
Water	210	291	360	324
w/c	0.6	0.6	0.6	0.51
Plasticizer	1.0% m.c.			
Sand 0-2mm	682	1453	1169	1241
Coarse aggregate 0-8 mm	1050	-	-	-

THE RESULTS AND DISCUSSION

Figure 3 shows the relationship of yield stress of mortar Z1, Z2 and Z3 and fresh concrete in the system at different temperatures, obtained in the tests. Figure 4 shows the influence of temperature on the rheological properties of fresh concrete of cement with high calcium fly ash and containing high calcium fly and other mineral additive: siliceous fly ash V, limestone LL and slag S. The study included measurement of rheological properties of the fresh concrete and was made on the basis of the corresponding components of mortars but in different proportions, depending on the method of designing. Rheological properties were determined for three different temperatures. The table 4 shows the correlation coefficient for the yield stress and plastic viscosity for the fresh concrete and mortar (Z1, Z2, Z3). The table shows that the best matched results of the rheological parameters for the scheme mixture – mortar, has the mortar Z1. For the mortar Z1, the volume of paste was regarded as the product of the coarse aggregate surface area and thickness of the founded coating paste. Studies show that the rheological properties of mortars Z1 show similar trend of changes, due to the influence of tested temperatures, as well as the fresh concrete. In the temperature of 30^{0}C, for measuring the plastic viscosity of mortar Z1, there is an insufficient number of measurements, due to the stiffness of the fresh concrete. Therefore, the results are not reliable for the plastic viscosity measured at 30^{0}C. For the composition mortar Z2, which was similar to the composition of the fresh concrete, without adjustments, it was difficult to analyze rheological parameters, due to fluctuated within the limit of measurement error of the device. Mortars were characterized by a high degree of liquidity. The results showed that together with the increase of temperature, the rheological parameters of fresh concrete and mortar Z1 and Z3 made on the basis of cement with high calcium fly ash are increasing and fresh concrete is losing its workability. For fresh concrete based on multi-component cement, with the addition of high calcium fly ash W and other additives, such as: fly ash silica V, limestone LL and slag S the increase of temperature does not result in a clear trend. Introduction of the cement additive of high calcium fly ash and lime LL resulted in less sensitivity of fresh concrete to temperature changes. Together with the increasing amount of high calcium fly ash in the fresh concrete increases the sensitivity to the changes of yield stress. For the fresh concrete based on cement CEM II/B-W the increase of temperature causes an increase in yield stress parameter for twice the value.

Figure 2. The dependence of yield stress of fresh concrete and mortar at various temperatures.

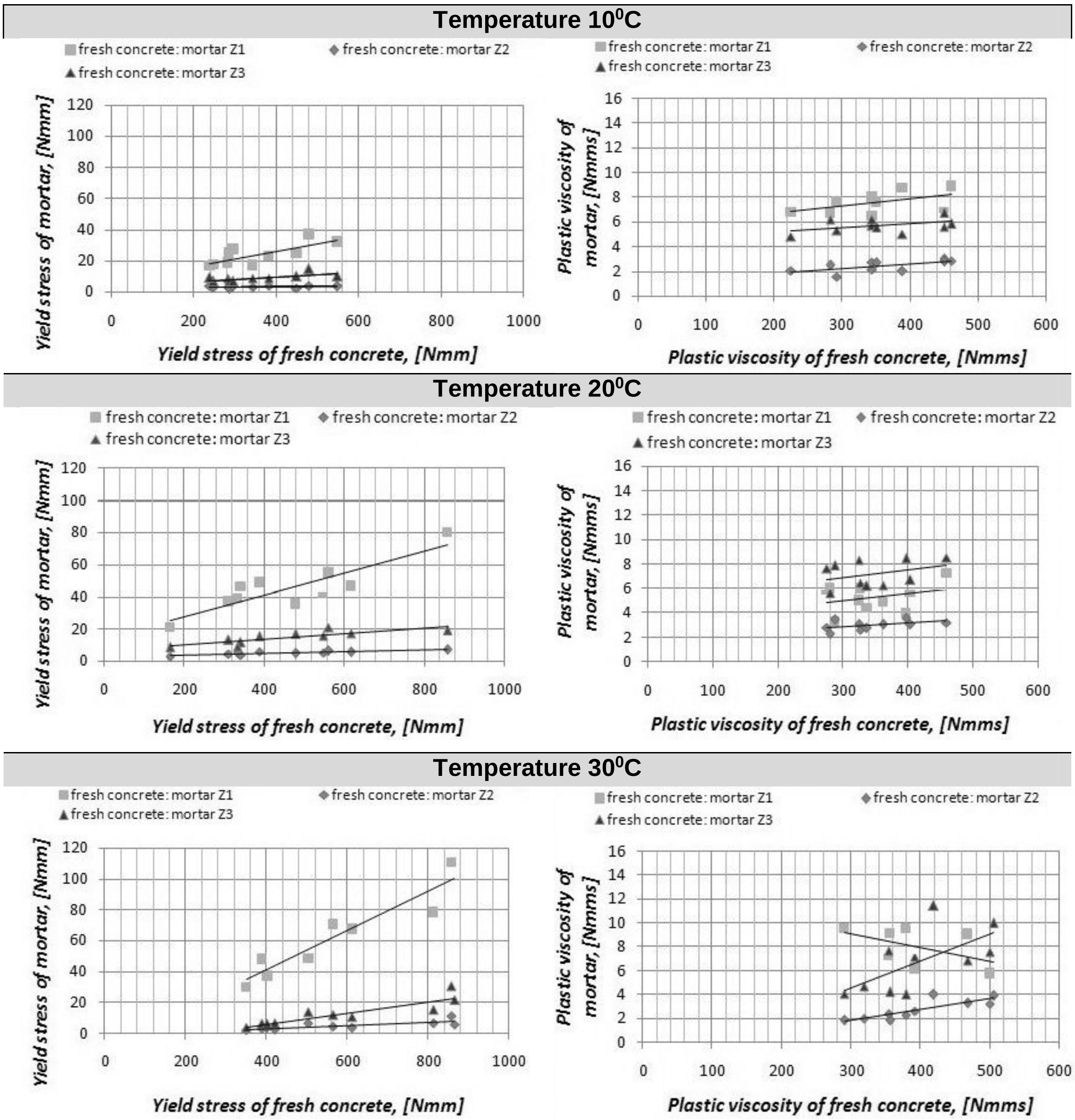
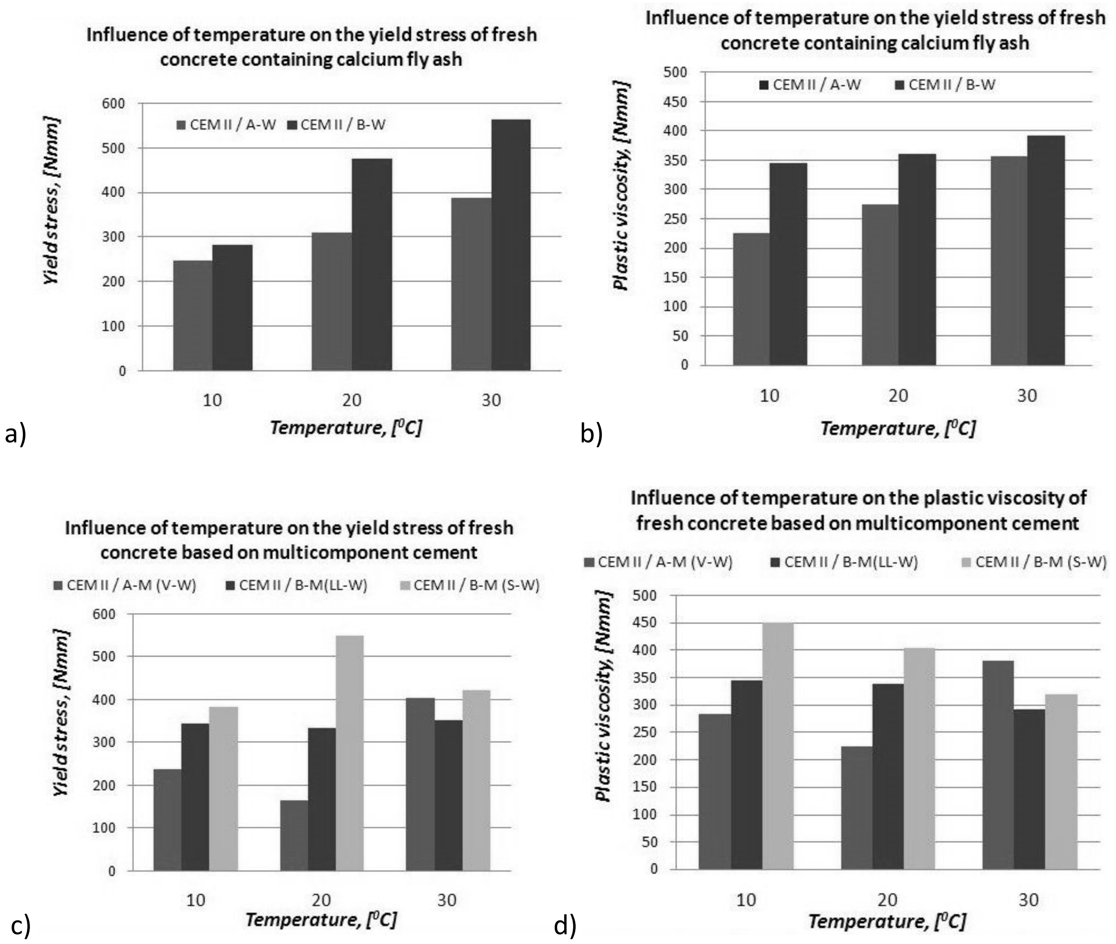


Table 4. The correlation coefficient for the yield stress and plastic viscosity for the fresh concrete with mortar (Z1, Z2, Z3).

	The correlation coefficient, R					
	Yield stress g, [Nmm]			Plastic viscosity h, [Nmms]		
	Fresh concrete : Mortar Z1	Fresh concrete : Mortar Z2	Fresh concrete : Mortar Z3	Fresh concrete : Mortar Z1	Fresh concrete : Mortar Z2	Fresh concrete : Mortar Z3
Temperature 10^0C	0.76	0.40	0.69	0.55	0.64	0.43
Temperature 20^0C	0.87	0.79	0.82	0.32	0.49	0.35
Temperature 30^0C	0.94	0.71	0.89	0.5 (low data)	0.84	0.64

Figure 3. The influence of temperature on the rheological properties of fresh concrete: a, b) containing high calcium fly ash, c, d) based on multicomponent cement.



CONCLUSION

The rheological properties of the fresh concrete depending on the rheological properties of mortar (Z1, Z2, Z3) is presented this paper. It has been shown that the way to achieve the possibility of predicting the influence of technological factors on the rheological properties of fresh concrete based on the properties of mortar is to adopt a an appropriate method to determine the composition of the mortar. The mortar (Z2) which composition stems directly from the composition of the fresh concrete turns out to be too fluently. Intergranular space overflow sand by uncorrected amount of paste is so large that the effect of capillary effect and friction between particles aggregate for the change of rheological parameters caused by such as temperature is the limit of error of the method used for their determination (for mortar Z2). With the correction by subtracting the amount of water, because of the water demand coarse aggregate for founded consistency obtain the mortar which is better responds to maintaining the behavior of the fresh concrete. However the main disadvantage of this method is a different value of the w/c ratio for mortar (Z3) and for fresh concrete. The highest compatibility with the behavior of fresh concrete due of temperature is characterized by a mortar Z1. The composition of the mortar was determined by subtracting cement paste, which covers the grain of coarse aggregate. Subtracting cement paste makes the w/c ratio of mortar and fresh concrete is the same and that the degree of overflow cavity fine aggregate is reduced. Therefore a greater role in the changes workability of mortar can play intergranular friction and capillary integrity of aggregate.

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