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RESEARCH ARTICLE

Effect of Calcareous Fly-ash Processing Methods on Rheological Properties of Mortars

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Abstract

The paper presents the results of research into the influence of calcareous fly ash (CFA) processing methods on the rheological properties of mortars. The study consisted of a comparison of changes of the rheological properties (plastic viscosity and yield value) of the mortars during 90 minutes when CFA, unprocessed or processed by grinding, grain separation, or selective collection from the filter, was used as a substitute for a part of the cement. The results show that processing of CFA decreases its negative influence on the rheological properties; the efficient methods are separation or grinding, while the effect of selective collection is almost insignificant.

Keywords

calcareous fly ash, rheological properties, fly ash processing methods, cement mortars, workability

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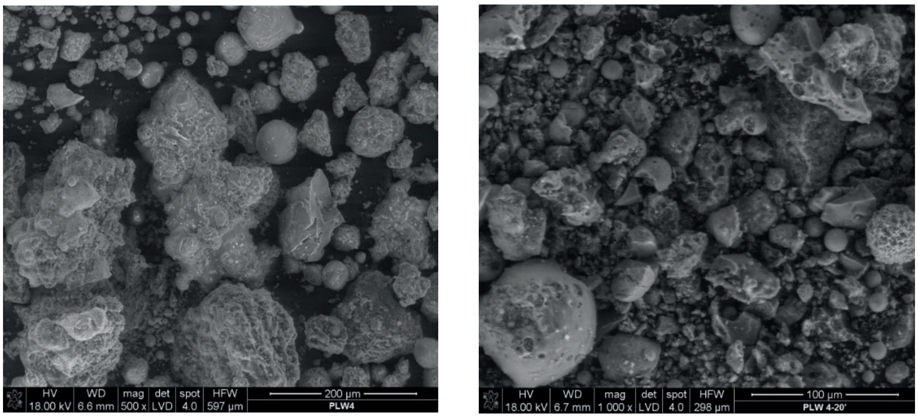
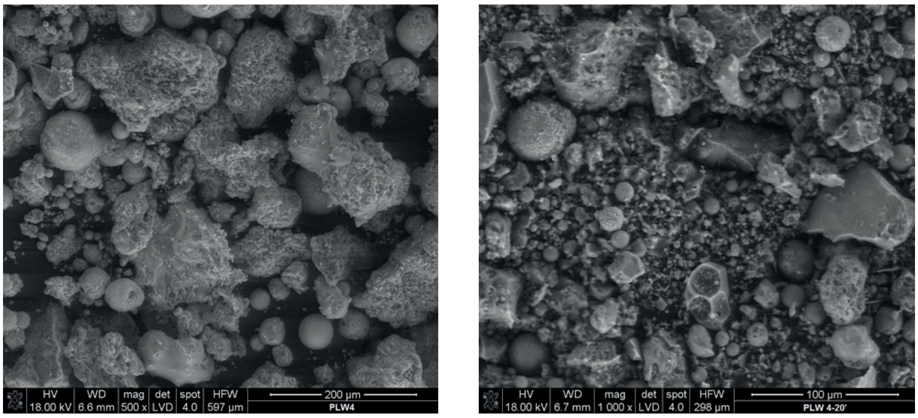
1 Introduction

Calcareous fly ash (CFA) is produced as a result of burning brown coal in conventional furnaces in large amounts; in Poland, about 5 million tonnes of CFA is produced every year [1]. One of the ways of managing this waste is by using it as an additive in cement or concrete [2–6]. However, extensive use of CFA encounters important limitations. These include: (1) the characteristics of the CFA's chemical composition, especially the high content of free lime as well as sulfate, which lead to a risk of a potential negative influence on the properties of concrete, (2) the variability of the physicochemical properties of CFA, which makes it difficult to control the properties of concrete, and (3) the high water demand of CFA, which has a negative impact on the workability of fresh concrete, especially with regard to the aspect of loss of workability over time [2, 4, 7–11]. Moreover, so far, only a small number of systematic researches on the influence of CFA on concrete properties are available [1–5]. In order to check the possibilities and conditions for the efficient use of CFA in concrete technology, a wide and systematic research programme was carried out and its results are shown in [12, 13]. The research was carried out for fly ashes from the Bełchatów power plant, as these fly ashes are distinguished by having the most useful properties for cement and concrete technology [18]. It was found that the CFA is characterized by both very favourable pozzolanic and hydraulic properties and high long-term activity [14]. It has been shown that the presence of CFA does not usually adversely affect the mechanical properties and durability of hardened concrete and sometimes it even improves them [16, 19–21]. It was confirmed that increasing the amount of CFA significantly worsened the rheological properties (increasing yield value and plastic viscosity) and workability of fresh concrete; when the amount of raw CFA exceeds 20% of the binder mass, obtaining a mix with the required workability becomes difficult [22]. In order to obtain fresh CFA concrete whose workability is analogous to that of fresh concrete without CFA addition, it is necessary to use a larger amount of plasticizer or superplasticizer; when 30% of the cement is substituted with CFA, more than double the amount of superplasticizer must be used, and even then, the fresh CFA concretes show a fast loss of workability [5]. The mechanism of CFA's negative influence on the rheological properties of mortar is connected to its increased water demand. This in turn results primarily from the morphology of its grains and their chemical and phasic composition. Figure 1 shows grains of fly ash characterized by asymmetrical shape and high porosity. Removing the large porous grains from CFA reduces the water demand, which in turn reduces the impact on the workability. CFA can be processed by grinding, separation, and removal of the coarse fraction and selective collection from particular electro-filter zones. Processing the CFA by grinding or separation reduces the water demand [16, 18]. In the case of processing by grinding, large porous grains are broken down and destroyed (Fig. 1) and an active part of the fly ash is exposed to water. In the case of grain separation, these grains are simply removed. In the case of selective collection, CFA from which the adverse fractions have been removed is gathered from the appropriate zone of the electro-filter and can be used as an additive in cement or concrete.

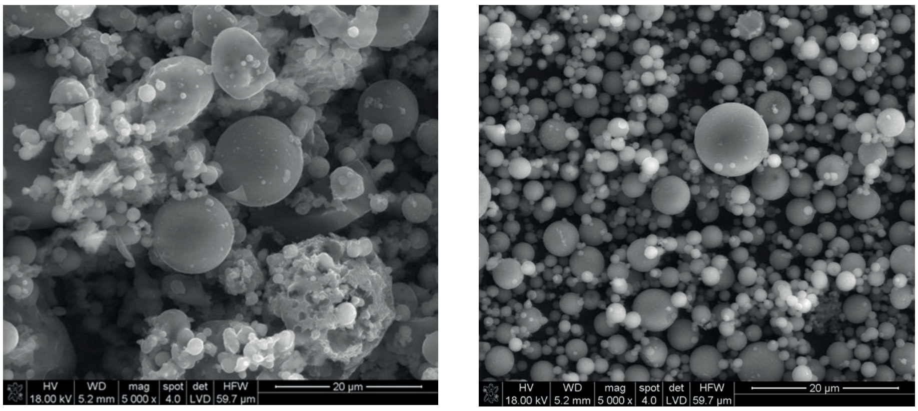
In this paper, the influence of CFA processed using different methods on the rheological properties of the mortars is presented and discussed. The main goal of the research was to determine the usability of these methods of processing the CFA with regard to the workability of mortars, and in broader terms, the workability of fresh concrete. In a general way, the research may contribute to popularizing the possibility of CFA use in cement and concrete technology, which would be very beneficial for protection of the environment.



a - raw Calcareous Fly Ash



b - processed Calcareous Fly Ash



c) Siliceous Fly Ash of category N
d) Siliceous Fly Ash of category S

Fig. 1 Morphology of calcareous and siliceous fly ash

Table 1 Research plan

Cement (acc. Tab. 4)	CFA (acc. Tab. 2) (content, %)	Processing method			
		grinding	grinding rate	separation	selective collection
G	A (10, 20, 30)	AG(10, 20, 30)	AG+ (10, 20, 30)		
	B (10, 20, 30)	BG(10, 20, 30)	BG+, BG++ (20)		
	C (10, 20, 30)	CG(10, 20, 30)		DS over 0,09 mm removed (20)	
	D (10, 20, 30)	DG(10, 20, 30)		ES over 0,063mm removed (20)	
	BL3 (20)				BL3 zone I (20) BL3 zone II (20) BL3 zone III (20)
N	A (20)	AG (20)			
	B (20)	BG (20)			
	C (20)	CG (20)			
	D (20)	DG (20)			
O	A (20)	AG (20)			
	B (20)	BG (20)			
	C (20)	CG (20)			
	D (20)	DG (20)			

Table 2 Composition of CFA

CFA	Loss of ignition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	TiO2	CaO_{free}
A	2.56	33.47	19.19	5.37	31.18	1.84	4.33	0.11	0.31	1.21	3.43
B	2.67	45.17	20.79	4.58	20.6	1.49	2.5	0.19	0.23	1.37	1.18
C	2.12	40.98	19.00	4.25	25.97	1.73	3.94	0.14	0.13	1.52	1.07
D	2.70	47.4	20.5	4.5	19.1	1.5	2.3	0.20	0.20	1.44	1.00
CFA collected from different zones of electro-filter											
BL3	4.44	42.42214	18.92	4.20	23.88	1.42	2.67	0.14	0.21	1.32	1.735
BL3 zone I	10.69	49.77	17.05	2.48	15.29	1.18	1.34	0.11	0.18	1.62	0.83
BL3 zone II	3.66	33.43	15.99	4.09	34.20	1.87	4.24	0.12	0.33	1.60	2.72
BL3 zone III	2.94	29.00	15.21	4.88	35.59	1.87	7.84	0.16	0.45	1.51	2.13
CFA after separation of fractions over 0,063 and 0,09 mm											
CS	1.02	38.05	18.40	4.46	29.35	1.84	4.73	0.12	0.15	-	1.56
DS	1.29	42.11	19.55	5.22	22.73	1.6	3.77	0.17	0.24	-	2.01

Table 3 Properties of CFA

CFA	CFA fineness			Blaine specific surface. cm2/g		
	raw	ground G/G+/G++	separation S	raw	ground G/G+/G++	separation S
A	36.4	23/10.5/-		2860	3500/3870/-	
B	57.2	16.7/-/-		1900	3700/-/-	
C	46.3	20.8/10.2/5.2	29.1	2370	3520/3940/4210	3100
D	59.2	20.3/-/-	17.4	2258	3750/-/-	3650
CFA collected from different zones of electro-filter						
BL3	54.6	8.2/-/-		1950	4060	-
BL3 zone I	86	-	-	760		
BL3 zone II	17	-	-	3750	-	-
BL3 zone III	1.6	-	-	4380	-	-

2. Experimental details

2.1 Research plan

In the research, the influence of the CFA processing method on the rheological properties of mortars with addition of up to 30% CFA during 90 minutes was determined.

The following factors were investigated:

- processing method:
  - unprocessed (raw CFA),
  - grinding in a ball mill and grinding rate,
  - separation and removal of 0.09 and 0.063 mm fractions,
  - selective collection from different zones of the electro-filter (zones I, II, and III coming in successively at ever greater distances from the combustion chamber);
- CFA type (four batches of CFA with the properties shown in Tables 2 and 3, sampled in a time range of one year (once every three months) from intermediate reservoirs of Bełchatów power plant);

Table 4 Cements composition

Cement	SiO2	Al2O3	Fe2O3	CaO	SO3	Na2Oe	C3S	C2S	C3A	C4AF	Spec. surf. [cm2/g]
G	20.5	4.89	2.85	63.3	2.76	0.73	65	10	8.1	8.7	3500
N	20.9	4.97	2.8	63.9	2.77	1.06	64	12	8.4	8.5	4150
O	20.8	6.3	2.85	64.4	2.80	0.74	58	14	11.8	8.7	4180

- CFA content (CFA was added as a substitute for 20% of the cement mass; in the case of the grinding processing method, CFA was added as a substitute for 10, 20, and 30% of the cement mass);
- cement type (three CEM I 42,5 cements with the properties shown in Table 4).

The research plan is shown in Table 1.

2.2 Properties of the materials and composition of the mixes

The composition and selected physical properties of the unprocessed and processed CFA used in the research are compiled in Tables 2 and 3. The research was carried out for fly ashes from the Bełchatów power plant. The analysis of existing standards and guidelines shows that CFA could be used as the main constituent of cement [15, 17, 18]. Its use as a mineral additive in concrete is problematic. Standard [27] does not in fact provide for the use of CFA as a mineral additive in concrete, and standard [28] does not cover the scope of fly ashes with CaO contents higher than 10%. On the other hand, the requirements for CFA used as a mineral additive for concrete are defined in the American standard [29]. Unprocessed CFA met these requirements in terms of chemical composition and activity [14, 16, 18] but failed to do so in terms of fineness (maximum retention of 34% on a 45 µm sieve). After processing by grinding or separation, the requirement for fineness lower than 34% is always met. The fly ashes from the selective collection met the requirements of [29] only in case of the CFA collected from zone II. In other cases, the requirements concerning unburned carbon (CFA from zone I) and SO_3 (CFA from zone III), among others, are significantly exceeded. Fluctuations in the chemical composition and properties of the CFA are significant, especially with regard to the amounts of CaO, SO_3, and Na_2O. However, it should be noted that the ashes are characterized by relatively low changeability of the amounts of SiO_2 and Al_2O_3 and low loss on ignition. Due to separation, the loss on ignition of CFA is significantly lower.

The properties of the three CEM I 42.5 cements used in the research are presented in Table 4. The cements were collected from different cement plants. In general, the research was conducted using cement G, and the influence of cement type was investigated for CFA processed by grinding. The cements chosen differed significantly in terms of Na2Oe content (cement N differed from cements G and O), C3A content (cement O differed from cements G and N), and specific surface (cement G differed from cements N and O).

In order to eliminate the influence of the type and grading of sand on the rheological properties of mortars, the sand used was EN 196-1 CEN model sand (2 mm max.). The mixture proportions of mortars were based on standard mortar proportioning according to [30] but with the w/c ratio changed to 0.55. The mixture proportions are shown in Table 5.

Table 5 Composition of mortars for testing the rheological properties

Constituent	Amount [g/batch]
w/(c+plw)	0.55
Cement	450/405/360/315
CFA	-/45/90/135
Water	247.5
Standard sand	1350

2.3 Testing methods

It is commonly accepted that the rheological behaviour of mortar (and concrete) may be sufficiently described by the Bingham model according to the equation:

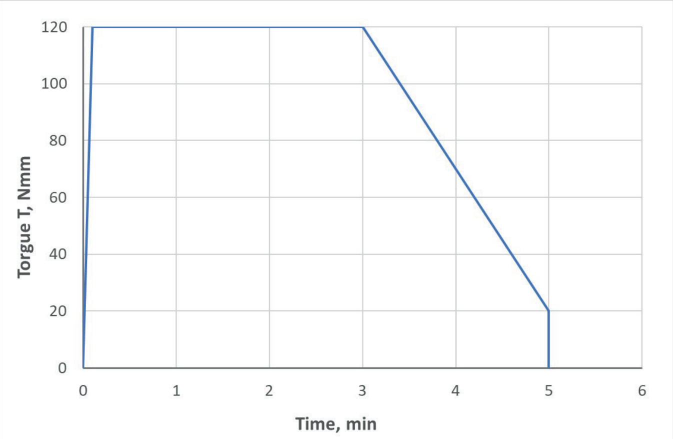
$$\tau = \tau_0 + \eta_{pl}\dot{\gamma} \quad (1)$$

where τ (Pa) is the shear stress at the shear rate γ (1/s), and τ_0 (Pa) and η_{pl} (Pas) are the yield stress and plastic viscosity, respectively. The yield stress τ_0 determines the value of shear stress necessary to initiate the flow. When the shear stress τ surpasses the yield stress τ_0, flow of the mixture occurs, and the resistance of the flow depends on the plastic viscosity η_{pl}; the higher the plastic viscosity of the mixture, the slower its flow. The parameter of particular importance for workability of the mixture is the yield stress τ_0. Its value determines the occurrence of flow of the mixture, and, in consequence, the accurate realization of the technological processes of concrete production. The technological meaning of the plastic viscosity η_{pl} is marginal in normal concretes. However, in the self-compacting mixtures and mixtures characterized by a low w/c ratio and high flow degree (low yield stress τ_0) obtained thanks to the addition of superplasticizer, the plastic viscosity η_{pl} is of significance for their workability and stability. It also determines the ability of the self-compacting mixtures to fill formworks to capacity and to self-deaerate.

The rheological parameters of mortar or fresh concrete can be measured by applying no less than two considerably different rotation speeds N and then measuring the resulting torque T. The rheological parameters are determined by regression analysis according to the relation:

$$T = g + h\,N \quad (2)$$

where g (Nm) and h (Nm s) are rheological constants corresponding to the yield stress τ_0 and plastic viscosity η_{pl}, respectively [23]. After determining the measurement constants of the rheometer one may, if necessary, represent the values g and h in physical units. The rheological properties of the mortars were determined after 5 and 90 minutes by rheometric test using a Viskomat NT rheometer. The measuring procedure and exemplary measurements are presented in Fig. 2. According to [24], when using apparatus like the Viskomat NT, τ_0 = 7.9 g and η_{pl} = 0.78 h, but all results are given below in terms of yield stress g and plastic viscosity h. The theoretical basis and rules for rheological measurements are discussed widely in monographic studies by [23, 25]. It should be noted that mortar can be used in the selected concrete constituent materials, in the design and development of rheological properties of concrete, and in quality control to detect variations in different batches of cement or admixtures [25, 26].



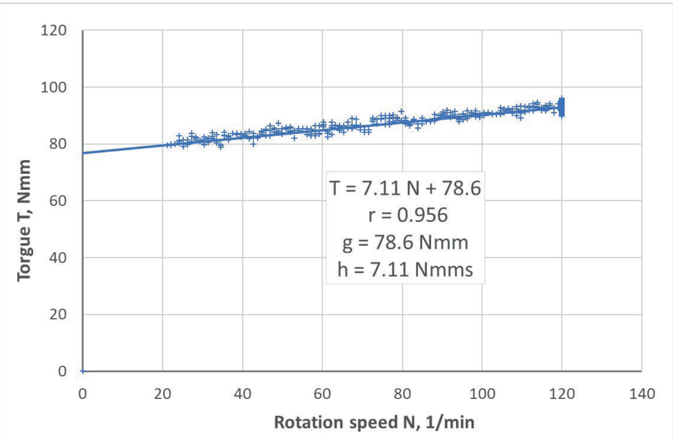


Fig. 2 Measuring procedure and example of measurement of rheological properties of mortars

Water demand was determined according to the methodology presented in Annex B of the standard [28]. The amount of air entrapped in the mortar was determined according to [31]. The setting time was determined according to [32]. It should be noted that methods of testing the setting time of cement and air content of mortars according to European standards [31, 32] are different from those recommended by ASTM [33, 34]. The heat of hydration of the cement was determined by TAM Air isothermal micro-calorimeters. With this apparatus, one determines the amount of heat in Joules per gram that is emitted in isothermal conditions during cement hydration from the moment of its contact with water. The heat stream that forms during the reaction of an unhydrated cement sample with water and that of an inert referential sample of analogous heat capacity are measured. The measurement was conducted on binder samples (cement G with 20% CFA) weighing 5 g, mixed with 2.5 g of water. The water/binder ratio (w/b) of samples was 0.5. During the measurement, the temperature of the cement paste was 20 oC. The measurement of the heat of hydration lasted 72 hours.

3 Results and discussion

The results of the influence of raw and processed CFA on the properties of mortars are compared in Figs. 3–7 and Table 6. The influence of CFA on the heat emitted is presented in Table 7.

Table 6 Influence of CFA on mortar properties and setting time of cement (CFA – 20%)

CFA type (acc Tab.3)	Water demandness %	Air volume %	Initial setting time. min
	CEM G		
0	100	8.2	182
A	108	2.8	315
AG	104	2.5	317
AG+	102	2.5	320
B	112	4.2	300
BG	105	2.2	284
BG+	104	2.3	310
BG++	104	2.4	311
C	110	3.5	246
CG	102	2.9	289
CS	-	2.8	-
D	110	3.0	280
DG	105	2.0	304
DS	102	2.5	290
BL	119	-	-
BLG	106	-	-
BL3 zone I	136	-	-
BL3 zone II	106	-	-
BL3 zone III	92	-	-
	CEM N		
0	-	5.0	176
A	-	2.7	310
AG	-	2.2	322
B	-	2.4	287
BG	-	3.5	279
C	-	3.9	256
CG	-	2.9	240
	CEM O		
0	-	6.1	191
A	-	2.5	330
AG	-	2.8	325
B	-	3.4	311
BG	-	2.9	302
C	-	3.1	276
CG	-	2.5	253

Table 7 Influence of CFA on the heat emitted during hydration of cement G - (CFA – 20%)

Ash	Amount of heat emitted [J/g] during hydration after time *t* (from the contact of cement and water)					
	10 min	1.5 h	12 h	24 h	48 h	72 h
CEM G	2.215	10.770	66.272	149.100	224.272	255.462
A	2.629	13.252	63.797	130.773	210.558	240.350
AG	2.950	14.218	63.986	137.196	212.532	240.657
B	2.981	12.321	57.819	124.276	194.661	220.385
BG	3.654	13.416	60.363	132.559	203.306	229.780
C	3.193	13.137	59.815	126.855	198.838	224.979
CG	3.508	14.131	61.970	132.705	203.890	230.541
CS	3.386	13.451	60.476	129.238	201.73	228.218
D	3.362	14.138	65.968	126.463	205.352	232.393
DG	3.988	14.629	70.414	142.003	214.344	238.279
DS	3.870	14.361	68.993	136.217	211.748	234.442

The addition of the raw CFA in place of a part of the cement causes a significant increase of the yield value *g* and plastic viscosity *h* of mortars; after substituting 20% of the cement with raw CFA, the rheological parameters increase, on average, by 80 and 45%, respectively (Figs. 3 and 4). Moreover, CFA speeds up the growth of the yield value *g* in time, which has an insignificant influence on the changes in plastic viscosity *h* in time. The increase in the CFA content causes an increase of both rheological parameters, especially the yield value *g*, and speeds up the fluidity loss. When the CFA content was 20%, the mortar shear stress after 90 minutes was so high that it was usually impossible to perform the measurement of the mortar's rheological properties. When the CFA content was 30%, measurements were impossible for all tested mortars after just 5 minutes. It should be noted that CFA containing more fine fraction has a smaller negative influence on the workability. Generally, the obtained results remain in good correlation with relevant data from the literature [2–10].

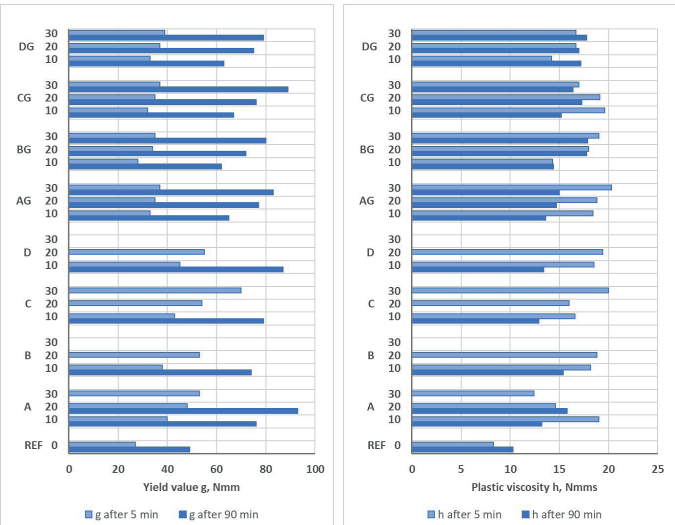


Fig. 3 Influence of the amount of CFA and its processing by grinding on rheological properties of mortars from cement G

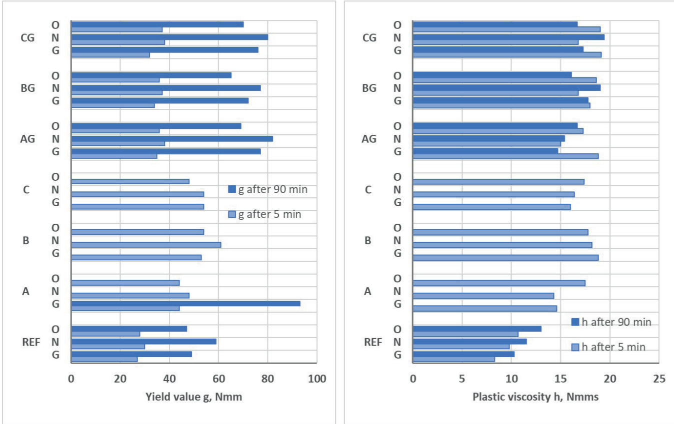


Fig. 4 Influence of CFA processing by grinding on rheological properties of mortars from cement G, N, O

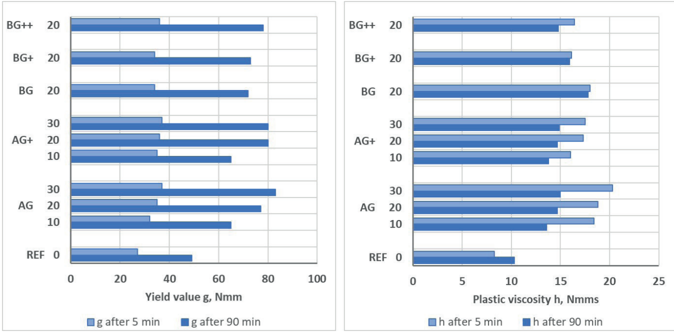


Fig. 5 Influence of the content and fineness rate of CFA on rheological properties of mortars from cement G

The addition of ground CFA causes the yield value *g* and plastic viscosity *h* of mortars to increase directly in proportion to the amount added (Figs. 3 and 4). However, the increase of the yield value *g* is significantly smaller than if the raw CFA is introduced; for example, introducing 20% raw or ground CFA causes the yield value *g* to increase, on average, by 81 and 24%, respectively. Processing of CFA has an insignificant influence on the plastic viscosity *h* of the mortars. In relation to raw CFA, the addition of ground CFA significantly lowers the range of changes of rheological properties of mortars over time. Processing makes it possible to obtain mortars containing up to 30% CFA whose acceptable workability is preserved for at least 90 minutes. However, range of changes of the rheological parameters over time of mortars with ground CFA remains clearly higher than that of the control cement mortars. For example, the yield value *g* of mortars without CFA addition increases to 22 Nmm, and for mortars with 10, 20 and 30% ground CFA, to 31, 39, and 41 Nmm, respectively, on average.

The addition of CFA with the > 0.09 mm fraction removed (DS type CFA) and with the > 0.063 mm fraction removed (CS type CFA) causes an increase in the yield value *g* and plastic viscosity *h* of mortars (Fig. 6). The increase in yield value *g* is clearly lower if the raw CFA is used and insignificantly lower (DS) or similar (CS) if the ground CFA is used. The increases of the yield value g over time of mortars with ground and separated CFA are similar. The method of CFA processing does not affect the plastic viscosity *h* of the mortars. The effect of the separation rate of grains over 0.09 or 0.063 mm is generally insignificant, and it can be concluded that the removal of fractions over 0.09 mm, which are composed of porous grains of unburned carbon, is decisive for the workability of mixtures.

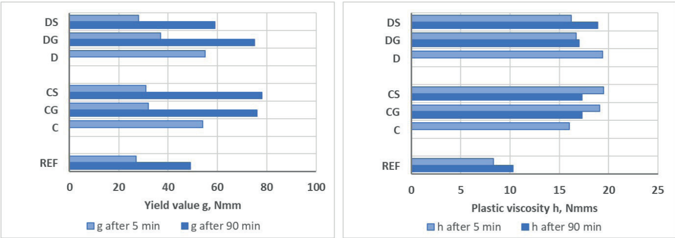


Fig. 6 Influence of CFA with separated fractions over 0,09 mm (DS) and over 0,063 mm (CS) on rheological properties of mortars from cement G

The influence of the addition of CFA collected from different zones of an electro-filter on the rheological parameters of mortars is shown in Fig. 7. CFA from zone I (BL1-type CFA) is characterized by a high content of unburned coal and grains sized over 0.045 mm. Its addition to mortars causes a quadruple increase of the yield value *g* and almost doubles the plastic viscosity *h* of the mortar as a consequence of the significant increase in water demand. Thus, CFA from zone I is not suitable for use in concrete technology. The addition of CFA from zone II (BL2-type CFA) causes an increase of the yield value *g* and plastic viscosity *h* of the mortar, similarly to the addition of ground CFA. The changes in the rheological properties of these mortars with time are also similar. The similarity of the influences of CFA from zone II and ground CFA on the mortar rheology may be connected with the fact that the values of fineness of CFA from zone II and ground CFA are similar. First, CFA from zone III (BL3-type CFA) does not influence the rheological properties of the mortars notably. However, in time, there is a significant increase of the yield value g, which is higher after 90 min than the yield value *g* of mortar with the addition of raw CFA. It is probable that a fast setting effect is caused by the presence of a vast amount of anhydrite (a high amount of SO_3) in the BL3-type CFA and consequent rapid setting process.

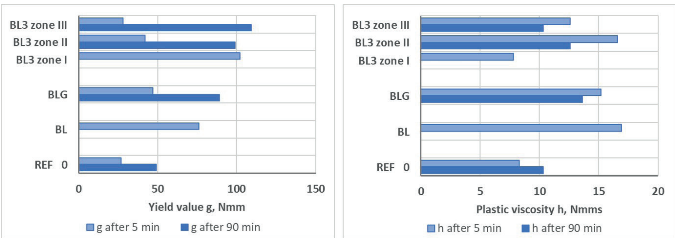


Fig. 7 Influence of CFA from selective collection on rheological properties of mortars from cement G

The rheological properties of the mortars depend on the chemical composition and physical properties of added CFA. The limited number of types of CFA tested, their complex compositions (the types of CFA used differ significantly from each other in terms of numerous composition parameters), and relatively narrow range of the change in composition parameters do not allow the formulation of general conclusions. However, it is worth noticing that when ground CFA is used, the influence of chemical composition is clearly weaker than when raw CFA is used.

As a result of adding the same type of raw CFA to mortars made of different cements, the yield value *g* can increase from 40 up to 120 and its plastic viscosity *h* increases from 30 to 90%. When ground CFA is used, its influence on the mortar rheology is considerably less dependent on the cement type. The research conducted does not make it possible to determine any general relationships between cement properties and rheological effects of introducing CFA. However, the research indicates that the influence of CFA on the mortar rheology is lower when cements with a higher content of C_3A and lower content of Na_2Oe are used.

The relationships in Figs. 8 and 9 indicate that the yield value g of mortars is inversely proportional to the fineness (defined by the amount of ash getting through a 0.045 mm sieve) and specific surface of CFA. This concerns both raw and processed CFA. Thus, together with increasing fineness (and specific surface), the negative influence of CFA on the workability of mortars decreases. It seems that the fineness of the CFA may be a good indicator of its utility in concrete technology with respect to mixture workability. It can be observed that the influence of the fineness and specific surface of ground CFA on the mortar rheology is weaker than in the case of raw CFA. The relationships in Fig. 5 show that the grinding rate of CFA is of lesser significance. Increasing the grinding rate (specific surface) of CFA causes only an insignificant decrease (A-type CFA) in the yield value *g* of mortars or does not even affect it (C-type CFA). Increasing the grinding rate causes a decrease of the plastic viscosity *h* of the mortar; these changes, however, are also not notable (max. 17%, usually not over 15%). The influence of the grinding rate of CFA remains small even after 90 min, and the consequent differences in the mortars' rheological parameters are not larger than 10%.

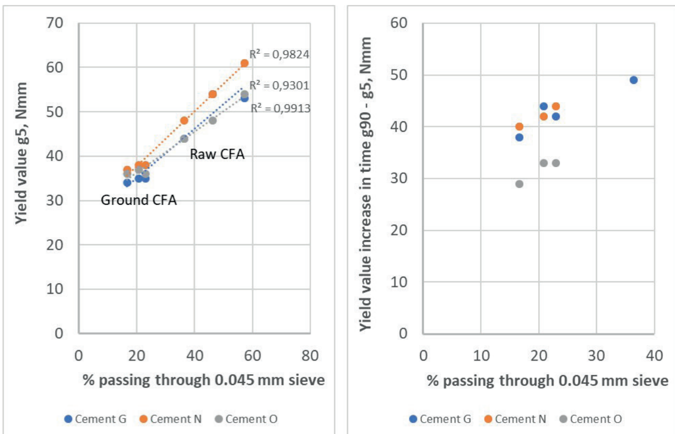


Fig. 8 CFA fineness vs yield value g and increase of yield value g in time of mortars (20% CFA type A).

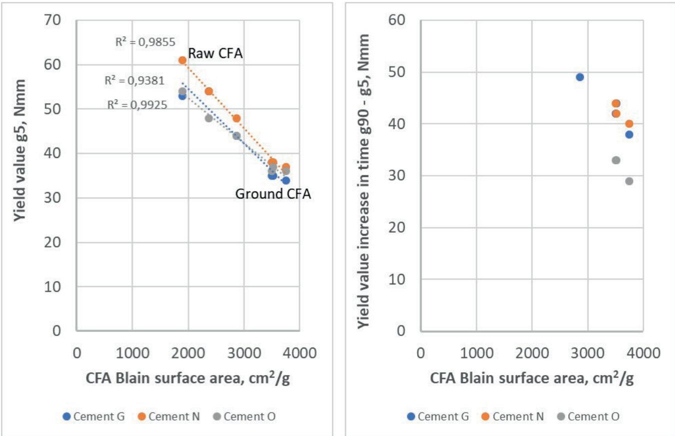


Fig. 9 CFA Blaine surface area vs yield value g and increase of yield value g in time of mortars (20% CFA type A).

The water demand of CFA is very high: replacing 20% of the cement with CFA causes the water demand to increase from 8 to 12% (10% on average) (Table 6). After processing by grinding or separation, the water demand of CFA decreases significantly but remains greater than that of cement. In the case of ground CFA, the water demand changes from 2 to 6% (4% on average) and in the case of separated CFA it changes from 3 to 4% (4% on average). The CFA collected from zone I of the electro-filter is characterized by significantly greater water demand than the unprocessed CFA (30%), CFA from zone II is analogous to CFA processed by grinding (6%), and CFA from zone III is analogous to cement. The results for the water demand of CFA, as one can expect, correlate well with the influence of CFA on the rheological properties of mortars. By testing the water demand of CFA, it is possible to judge its suitability in concrete technology with regard to workability.

The addition of CFA decreases the amount of air entrapped in the mortar. The effect is larger when CFA processed by grinding or separation is used, and at the same time, is slightly dependent on the type of CFA. The change in the amount of air may contribute to changes in the rheological properties of CFA mortars: the decrease in the amount of air usually contributes to increases in the yield value *g* and plastic viscosity *h* of mortars. Increasing the amount of CFA in the mortar does not influence the amount of air entrapped: the range of changes does not exceed 1% and the changes do not show general tendencies.

The presence of CFA affects the intensity of the hydration process in cement. Initially, up to 1.5 hour, the hydration heat of cement with the addition of 20% CFA is significantly higher than that of cement (50% higher on average after 10 minutes and 27% higher on average after 1.5 hours) and strongly dependent on the type of CFA. Ground CFA increases the hydration heat during this period more than raw CFA does (30 and 22%, on average, respectively). The large thermal capacity which is the first effect of the presence of CFA may be connected to the heat of wetting and the heat of hydration of free CaO, $CaSO_4$, and aluminate phases with ettringite formation. These processes result in a worse workability of the mortars and rapid workability loss in time. At the same time, it should be noted that despite the higher amount of heat emitted by ground CFA, the yield value *g* of mortars containing ground CFA is significantly lower than the yield value *g* of mortars with raw CFA. Taking this into consideration, it could be stated that the influence of CFA on the rheological properties of the mortar is caused not only by the raised water demand in the hydration process. The fact that a part of the water stays physically bonded in big, porous grains of unburned carbon is important for the mortar rheology. Eliminating those grains during grinding or separation makes it possible to lower the water demand of CFA and, in consequence, to reduce its negative influence on the mixture's workability. Despite the higher amount of heat emitted in the early phase of hydration, the presence of CFA delays the initial setting time of the cement. The initial setting time of cement in the presence of CFA is between 4 and 5 hours and is delayed by about two hours. It is worth noting that this indicates that faster workability loss of mortars with CFA is not an effect of faster hydration of the binder. The delay depends on the CFA type, but, at the same time, the influence of processing the CFA by grinding or separation is insignificant. Hydration heat after 1.5 hours is affected by the type of CFA to a lesser extent. During the time from 12 to 72 hours, the hydration heat of cement with CFA addition is lower than that of cement (by 10%, on average, after 72 hours) and the influence of processing gradually disappears.

4 Conclusions

From the investigation of the influence of raw and processed CFA on the properties of mortars presented in the paper, the following conclusions can be drawn:

1. The addition of raw CFA significantly increases both the yield value and plastic viscosity of mortars, speeds up the increase of yield value in time, and as a consequence significantly worsens the workability. The effect increases steeply with increasing amount of raw CFA. This influence of raw CFA on the mixture's workability makes its use in concrete technology problematic.
2. The addition of CFA processed by grinding or separation increases both the yield value and plastic viscosity of mortars and speeds up their changes in time, but to a significantly lesser extent than in the case of the use of raw CFA. In general, from the point of view of workability, CFA processed by grinding or separation can be successfully used in concrete technology, but only in amounts not exceeding 30%.
3. CFA from selective collection from zones I and III of the electro-filter is not useful in concrete technology from the point of view of workability. It should be noted that the CFA collected from zone III, whose influence on the mixture's properties is initially low, contributes to a

swift loss of workability with time. CFA collected from zone II is characterized by an influence on the rheological properties of mortars that is analogous to that of the CFA processed by grinding and may be used in concrete technology.

The results of the research show that with respect to the workability requirements, processing of CFA opens up the possibility of widening it possible use in concrete technology. For economic reasons, the production of cement with CFA as the main constituent is the recommended solution, and grinding is a routine process in cement production. The use of CFA processed in a separate process (grinding or separation) as a cement or concrete additive increases the cost significantly. Moreover, when employing the separation process to the processed material, it is difficult to use the waste material produced. The same problem also applies to CFA processed by selective collection.

Difficulties in obtaining and maintaining proper workability of CFA mixtures over time may be solved by using plasticizers or superplasticizers. The influence of CFA on the effectiveness of these admixtures needs further investigation. It must be noted that solving the problem of the negative influence of CFA on the mixture's workability will not on its own allow its utilization in concrete technology. Despite many studies, the influence of CFA on the properties and durability of cement composites remains.

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