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Analysis of Properties of Fly Ash Aggregate, Produced According to Silicatization Technology

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Abstract: The subject of this academic research work is production of ashy unburned gravel according to technology of two-bath silicatization with the usage of local fly ashes and bottom-ash mixtures of heat power plants in combination with liquid glass and calcium chloride which are non-inferior according to compression strength characteristic in cylinder and density to cement-ash gravel. Currently in building precast and mass concrete are extensively used for production of which natural aggregates are used. Unburned ashy gravel is used as a coarse aggregate for constructional and construction-insulating concretes. In Kuzbass, there is a lack of coarse light aggregate which is needed for organization of production of sectional envelope constructions and low- and high-rise cast-in-place house building constructions. In the course of the study, we have defined influences of some technological factors and approaches of ashy gravel's production on its strength characteristics. The results of this researches allowed suggesting technology for manufacturing ashy gravel according to the scheme of two-bath silicatization as well as to establish optimal technological parameters and regimes at which strength characteristics allow using it as an alternative effective aggregate for light concretes. Usage of wastes of fuel, energy and chemical industry for production of building materials, vacation of lands, occupied by storage of such wastes help resolving ecological issues that are related with environmental pollution of Siberian region.

Key words: Ashy unburned gravel, bottom-ash mixture, fly ash, two-bath silicatization, liquid glass, calcium chloride brine, curing of nodules, strength properties of fly-ash aggregate

INTRODUCTION

In our country developed net of heat power plants gives enormous volumes of waste products (ashes and slags) about 120 millions of tons each year. When used rationally and effectively for enlargement of raw material resources for various areas of national economy (primarily for industry of building materials), these ashes and slags may become the source of wealth for the nation.

Storage of such amount of wastes requires huge territories which cause a great negative impact on environment while these areas could be used in national economy for resolving environmental problems.

Thank to production of ashy aggregates for concrete, we could desist from the use of rock aggregates which would allow decreasing the volume of natural aggregates' mining and reduce operating expenses for keeping ash disposal areas (Dvorkin, 2007).

Usage of ashes and slags of heat power plants is currently not very expanded in our country. One of possible trends of application for ashes from HPP in building is production of unburned ashy gravel (Ganzhara and Stepakhin, 2001).

In Kuzbass, there is a growing lack of large light aggregate, needed for production of sectional envelope constructions and low- and high-rise cast-in-place house building constructions. Keramzite gravel, produced by plants of Kemerovo oblast may be substituted by ashy gravel of similar density and strength capacity.

ANALYSIS OF FLY ASH AND BOTTOM ASH MIXTURE

In Kuzbass State Technical University, there have been some researches performed, aimed at usage of fly ash of dry discharge and bottom ash mixture of wet discharge in combination of liquid glass and calcium chloride for production of ashy unburned gravel according to two-bath technology of silicatization in the course of which nodules are formed which are enough water- and weather-resistant and which are non-inferior

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according to compression strength characteristic in cylinder and density of cement-ash gravel, produced according to well-known technology (Khanov and Yudina, 1989) as well as the range of other well-known types of light aggregates.

For laboratory analysis, we have used local wastes of ashes and slags like: fly ash of Kemerovskaya GRES power plant and bottom ash mixtures of Kemerovskaya HPP. Chemical composition of wastes from heat power stations that were fired by coal from Kuznetsk contain small amounts of CaO (3-5%) and refers to acid ones (their cement-sand ratio equals 0.11-0.06). Such slags can't set solid independently, though they become hydraulically active in mixture with alkalis at steam treatment at the temperature of 90-95°C.

Surface of bottom ashes from electric stations of Kemerovo equals 2.1-2.23 g cm^{-3} and their specific surface ranges from 1800-3714 cm^2 g^{-1} which is lower than recommended values. Losses at ignition of bottom ashes were 2.25-4.8% which was lower than the value of permissible levels (5%). The best results were demonstrated by bottom ashes that were discharge dry from the boilers.

Average density of bottom ash mixture from Kemerovskaya HPP ranged from 780-1049 kg m^{-3}, grain composition contained large amount of particles that were <0.14 mm (27.73-34.2%) including <0.08 mm (35-36%); fineness modulus equaled 0.48-1.59.

Natural background gamma radiation of fly ash from Kemerovskaya GRES and bottom ash mixture from Kemerovskaya HPP is lover than permissible level in terms of sanitarian norms.

In the course of study, we used sodium liquid glass according to GOST 13078-81 in the view of aqueous solution of glassy sodium silicates which is produced on the base of waste products of Novokuznetsk plant of ferroalloys and calcium chloride according to GOST 450-77. In operating compositions specific density of liquid glass and operating concentration of calcium chloride was defined basing on results of investigations.

MANUFACTURING TECHNOLOGY FOR FLY-ASH AGGREGATE

In the course of investigations, during validation through elaboration of technology of nodules' production, we have used laboratory granulator, initially with manual rotation of plate which was 1000 mm in diameter with the depth of 150 mm. In accordance with data, stated in technical literature (Chulivin, 2006; Diamant, 2005), granulator's inclination was regulated from 25-45°. It was accepted that effective angle of slope equaled 25-30°. Experiments proved that the best formation of nodules was provided at plate's rotation with the speed of 15 rpm. This allowed substituting manual plate granulator with mechanic one, where with the help of worm gear optimal speed was reached which equaled 15 rpm.

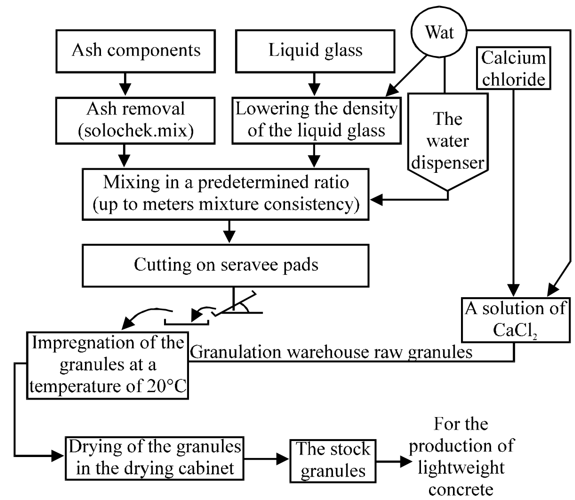

Fig. 1: Technological scheme of production of ashy unburned gravel according to two-bath silicatization technology

Pre-requisite during production of unburned ashy gravel is homogeneous inhibition of nodules with alkaline component that's why, it was deemed necessary to mix fly ash with all calculated amount of liquid glass and hardening water (Chumakov, 2006; Bazhenov, 2007). Agitation of mix was performed forcedly. Prepared feed had low-plasticity consistence and that's why, it didn't pelletize in granulator. Solution paste was sheeted out at laboratory desk which imitated continuous belt and was cut through the length and breadth with circular cutter onto "toffees" which were thrown onto moving plate of granulator. On granulator "the toffees" were pelletized at the same time, they rolled over side into accumulation tank from where they were loaded into the reservoir with calcium chloride where they were soaked in it during required period of time reactions between liquid glass and calcium chloride continued at a growing rate. Technological scheme of laboratory production of ashy unburned gravel according to two-bath technology of silicatization is presented at Fig. 1.

ANALYSIS OF FLY ASH GRAVEL

In the course of the research, we stated influences of some technological factors and techniques of production of fly ash gravel on its strength characteristics (Uglianitsa *et al*., 2014a-c).

Table 1: Strength characteristics of ashy gravel, depending on changes of specific density of liquid glass

Consumption of liquid glass for 1 kg of fly ash (kg m^{-3})	Additional consumption of water (kg m^{-3})	Specific density of liquid glass solution (g cm^{-3})	Compressive strength of ash gravel in cylinder (MPa): In 12 h after being in solution and 12 h of drying out at t = 40°C	Compressive strength of ash gravel in cylinder (MPa): In 12 h after being in solution and 60 h of drying out at t = 40°C
250	30	1.10	0.00	0.2
250	40	1.12	0.00	0.4
250	70	1.17	0.30	1.0
250	100	1.26	0.60	1.1
250	120	1.35	0.65	2.0
250	140	1.39	1.00	2.8
250	150	1.43	2.50	3.4

Table 2: Strength characteristics of ash gravel depending on changes in liquid glass consumption

Parameters	Values: 1	2	3	4	5
Consumption of liquid glass (Density of 1.4 g cm^{-3}, kg m^{-3})	100	150	200	250	300
Consumption of fly ash (kg m^{-3})	1000	1000	1000	1000	1000
Consumption of water (L m^{-3})	250	210	150	100	30
Total consumption of water solution of liquid glass aqueous solution and hardening water (kg m^{-3})	350	360	350	350	350
Actual density of liquid glass aqueous solution (g cm^{-3})	1.320	1.360	1.365	1.375	1.395
Retention time in solution of $CaCl_2$ at t = 20°C	12	12	12	12	12
Strength of ash gravel Mpa) (after (drying at t = 40°C during 12 h)	0.50	0.80	1.50	1.32	1.60

Influence of density of liquid glass on strength fly ash gravel's characteristics was investigated in the following way: specific density of liquid glass at its fixed rate flow of 250 kg m^{-3} was changed; initial mixture composition (mixture of ash gravel with liquid glass of specified density) was presented with additional amount of water for making the consistence low-plastic; produced ash gravel was being aged in liquid glass solution within 12 h at 20°C and was exposed to dry heat treatment at a temperature of 40°C within 12 and 60 h and later it was tested on compression in cylinder (after cooling out). Results of investigations of ashy gravel, produced on liquid glass of various density are presented in Table 1.

As it can be seen from Table 1, with increase of liquid glass' density, strength characteristics of ash gravel increase and with increase of time of dry heat treatment at a temperature of 40°C their compression strength in cylinder is invariantly increasing. This fact should be considered at setting recommended specific density of liquid glass for operating mode of nodules' production.

At the same time, one should keep in mind that strength of unburned gravel increases while I is being kept at a warehouse and especially at a temperature treatment of concrete, made on it.

Based upon these circumstances, one may preliminary recommend setting specific density of liquid glass solution in working compositions to values of 1.3-1.4 g cm^{-3} and time of heat treatment of nodules should be limited by 12-16 h.

With the purpose of definition of influence of liquid glass' consumption on strength characteristics of unburned ash gravel, we performed experiments in the course of which initial density of liquid glass (1.4 g cm^{-3}) and consumption of fly ash (91000 kg m^{-3}) were accepted as constant ones. Water consumption at various applications of liquid glass was set in the course of experiments in the way that low-plasticity consistence of the mixture could be kept. Nodules were soaked in calcium chloride solution for 12 h in chamber drier at a temperature of 40°C. Results of experiments are presented in Table 2.

As it can be seen from Table 1 as liquid glass consumption reduced, it was added with some extra amount of water for making its consistence low-plastic which led to total consumption of water solution of liquid glass and water in the range of 350-360 kg m^{-3}. At the same time, we could observe the change of initial density of water solution of liquid glass to the values of 1.32-1.395 g cm^{-3}. Decrease in density of water solution of liquid glass causes an impact on strength characteristics of ash gravel from 1.6-0.5 MPa.

Thus, considering all abovementioned experiments, we may say that total consumption of water solution of liquid glass, considering required consistence of the mixture should equal 350-360 k gm^{-3} while operating density of total solution of liquid glass, basing upon required characteristics of initial density of ash gravel should be accepted as 1.3-1.36 kg cm^{-3}.

Influence of density of calcium chloride water solution on strength characteristics of ash unburned

Table 3: Strength characteristics of ash gravel depending in changes in density of calcium chloride

Density of calcium chloride solution (g cm^{-3})	Time of holding nodules in solution (h)	Drying time of nodules at t = 60°C (h)	Nodules' compressive strength in cylinder (MPa)
1.08	12	12	3.0
1.10	12	12	3.1
1.15	12	12	3.5
1.30	12	12	4.7

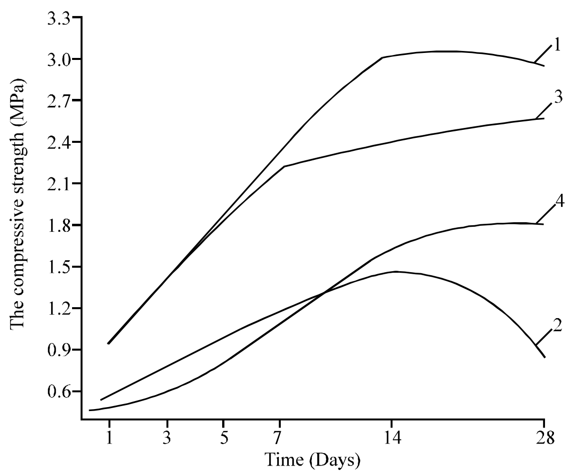

Fig. 2: Strength of ash gravel at compression in cylinder in 1-28 days of keeping in normal conditions, after being kept in hardener solution and drying at a temperature of 40°C during 12 h; 1) during 4 h; 2) during 8 h; 3) during 12 h; 4) during 16 h

gravel, produced according to technology of two-bath silicatization, appeared to be necessary. There is no information about concentration of calcium chloride solution in technical literature which could describe production of concrete products from mixture of sand and liquid glass which later were sunk into bath with hot calcium chloride solution (Uglianitsa and Isaenko, 2011; Uglianitsa and Solonin, 2013). In the course of performance of abovementioned experiments density of calcium chloride solution didn't change.

As it can be seen from Table 3, change in density of calcium chloride solution within the range of 1.08-1.3 g cm^{-3} causes no great changes to strength characteristics of nodules (in case they are soaked during 12 h).

Based on economic considerations, operating density of calcium chloride may be recommended to be within the range of 1.1-1.3 g cm^{-3}.

Analysis of influence of time and temperature of nodules' retention in calcium chloride solution on its strength characteristics was performed in the following way: seed nodules were soaked in calcium chloride solution and were retained there at a temperature of 20°C 4, 8, 12 and 16 h then they were dried at a temperature of 40°C during 12 h.

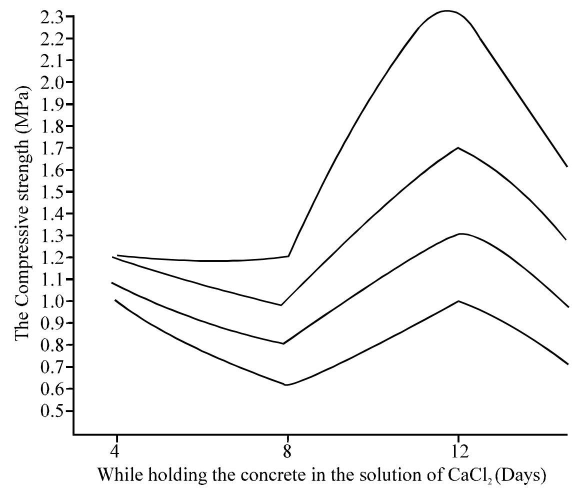

Fig. 3: Character of changes of ash gravel's density in 1-7 days depending on retention time in calcium chloride solution; 1) in 7 days; 2) in 3 days; 3) in 5 days; 4) in 7 days

Dynamics of increasing strength of ash gravel which was retained in calcium chloride solution for various periods of time is shown in Table 4 and at Fig. 2.

As it can be seen from Table 4 and Fig. 2, the highest subsequent strength at compression of nodules in cylinder was reached, when they were retained in calcium chloride solution within 4 and 12 h. At the same time as distinct from growth curve of strength of ash gravel's nodules which were kept in solution during 4 h for which at the age of 14-28 days insignificant but recessive character is typical, growth curve of strength capacities of nodules which were kept in calcium chloride for 12 h is of logarithmical increasing character.

Figure 3 demonstrates character of changes in strength of ash gravel in 1-7 days depending in time of retention in calcium chloride solution.

As it can be seen from Fig. 3 where we are demonstrated with the system of curves of 1, 3, 5 and 7 days compressive strength in cylinder after their retention in m chloride solution, optimal time of retention in solution at which high strength performance is kept, corresponds to 12 h. This optimal value for compressive strength should be accepted as technological character while setting time for soaking of nodules in calcium chloride solution at divided scheme of its production.

Analysis of influence of temperature mode and time of dry heat treatment of seed nodules of unburned ash gravel on strength characteristics was performed in the

Table 4: Strength compressive characteristics of ash gravel at various periods of retention time in calcium chloride solution

Composition of ash gravel			Retention in calcium chloride solution (h)	Strength of ash gravel at compression in cylinder (MPa, days)					
Fly ash ($kg\ m^{-3}$)	Liquid glass (L)	Water (L)		1	3	5	7	14	28
1000	250	100	4	1.0	1.1	1.2	1.2	3.0	2.8
1000	250	100	8	0.6	0.8	1.0	1.2	1.5	0.9
1000	250	100	12	1.0	1.3	1.8	2.5	2.0	2.6
1000	250	100	16	0.5	0.7	1.0	1.0	1.7	1.8

Table 5: Strength compressive characteristics of ash gravel at various temperature values during its "dry" treatment

Consumption of ash gravel'scomponents ($kg\ m^{-3}$)			Density of calcium chloride solution ($kg\ L^{-1}$)	Temperature of "dry"treatment during 12 h (°C)	Strength of ash gravel in cylinder at compression (Mpa)
Liquid glass (L)	Fly ash (kg)	Water (L)			
250	1000	100	1.3	20	0.2
250	1000	100	1.3	40	0.6
250	1000	100	1.3	60	2.5
250	1000	100	1.3	90	3.9
250	1000	100	1.3	100	3.0

following order: seed nodules, after being kept in calcium chloride solution were heated within 12 h in the following temperature ranges: 20, 40, 60, 80, 100°C. It was decided not to steam cure nodules but to perform "dry" treatment in chamber drier (Alexandre and Rita, 2014; Brozovsky *et al*., 2013; Alessandra *et al*., 2013).

Results of changes of compressive strength characteristics in cylinder of ash unburned gravel at various temperatures during its "dry" treatment are presented in Table 5.

As it can be seen from Table 5 as a temperature of "dry" isothermal mode of treatment of ash gravel increases, its compressive strength in cylinder increases, though it reaches its optimal value at a temperature of 90°C. This fact should be considered at setting operating mode of drying of ash gravel.

CONCLUSION

Investigations, performed in the course of this research, allowed to suggest technology of production of unburned ash gravel according to scheme of two-bath silicatization as well as et out optimal technological parameters and modes at which strength characteristics allow using it as an alternative effective aggregate for light concretes.

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